US009436520B2

(12) **United States Patent**
Itou

(10) **Patent No.: US 9,436,520 B2**
(45) **Date of Patent: Sep. 6, 2016**

(54) **INFORMATION PROCESSING DEVICE AND BARRIER SYNCHRONIZATION METHOD**

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(73) Assignee: **FUJITSU LIMITED**, Kawasaki (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 423 days.

(21) Appl. No.: **13/937,258**

(22) Filed: **Jul. 9, 2013**

(65) **Prior Publication Data**

US 2014/0026138 A1 Jan. 23, 2014

(30) **Foreign Application Priority Data**

Jul. 20, 2012 (JP) 2012-161392

(51) **Int. Cl.**
G06F 9/52 (2006.01)
G06F 9/38 (2006.01)

(52) **U.S. Cl.**
CPC ***G06F 9/522*** (2013.01); ***G06F 9/52*** (2013.01); *G06F 9/38* (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

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(Continued)

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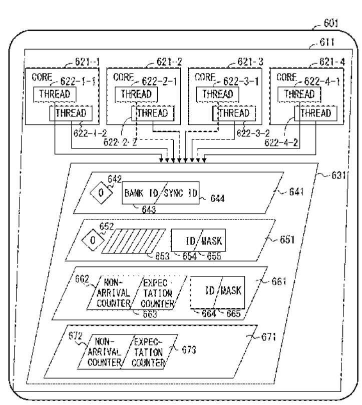
(74) *Attorney, Agent, or Firm* — Fujitsu Patent Center

(57) **ABSTRACT**

An information processing device includes a plurality of barrier banks, and one or more processors including at least one of the plurality of barrier banks. Each of barrier banks includes one or more hardware threads and a barrier synchronization mechanism. The barrier synchronization mechanism includes a bottom unit having a barrier state, and a bitmap indicating that each of the one or more hardware threads has arrived at a synchronization point, and a top unit having a non-arrival counter indicating the number of barrier banks yet to be synchronized. The bottom unit notifies of bottom unit synchronization completion when all the one or more hardware threads have arrived at a barrier synchronization point. The non-arrival counter decrements its value by 1 upon receipt of the bottom unit synchronization completion, and the top unit sets the barrier state to a value indicating synchronization completion when the non-arrival counter decrements to 0.

2 Claims, 52 Drawing Sheets



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Yamada, Kaito et al., "An Evaluation of Barrier Synchronization Mechanism Considering Hierarchical Processor Grouping", Technical Report of IEICE, The Institute of Electronics, Information and Communication Engineers, vol. 108, No. 28, ICD2008-20, pp. 1-6 (May 2008), Partial English Translation.

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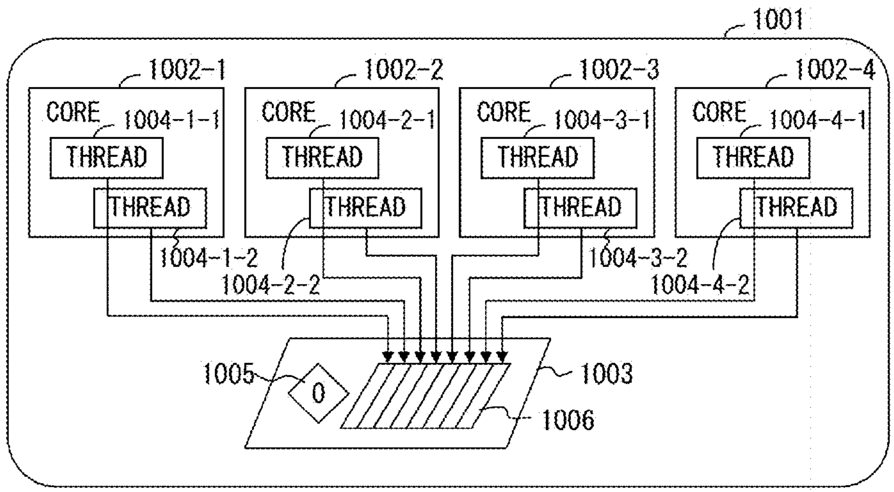
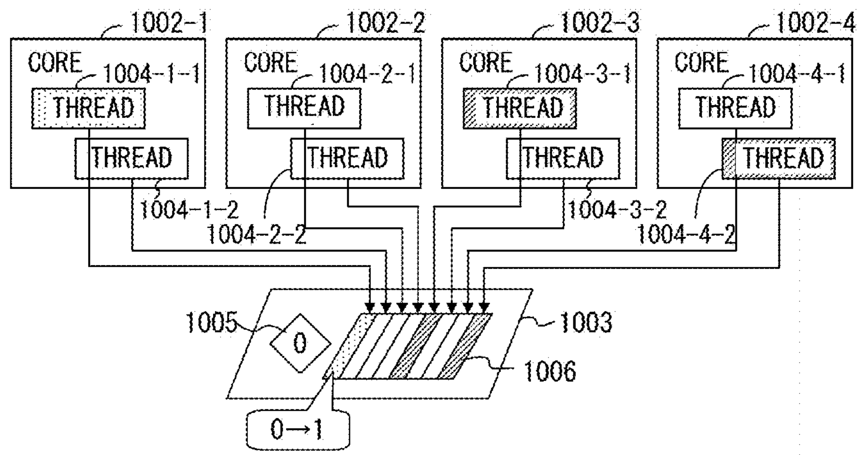


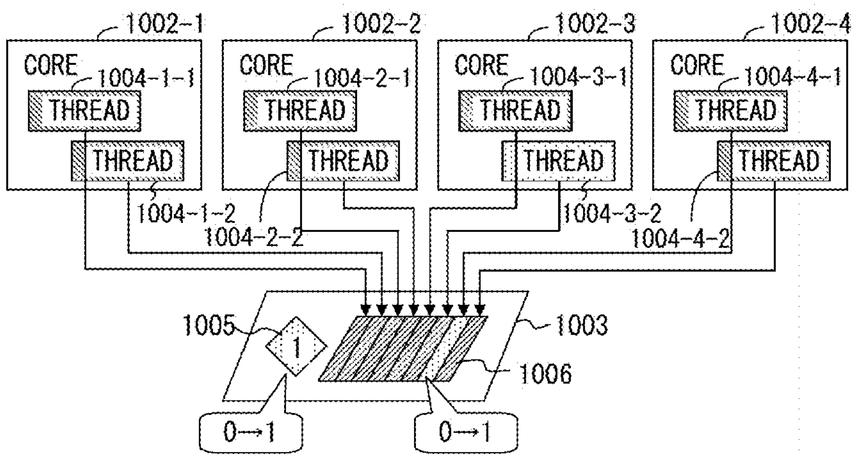
RELATED ART

FIG. 1A



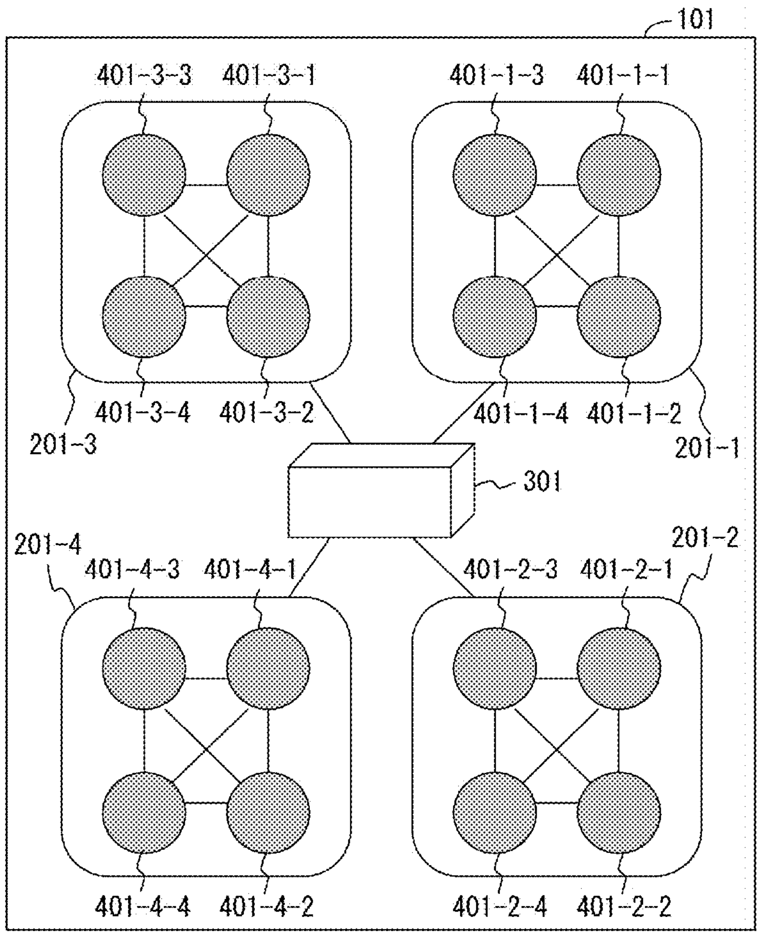
RELATED ART

FIG. 1B



RELATED ART

FIG. 1C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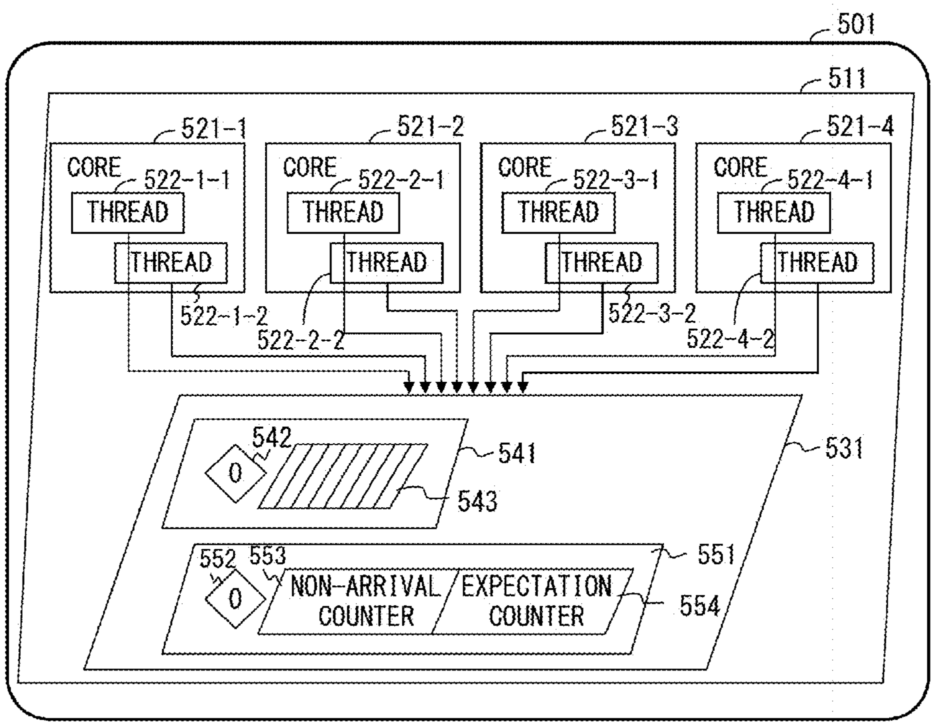
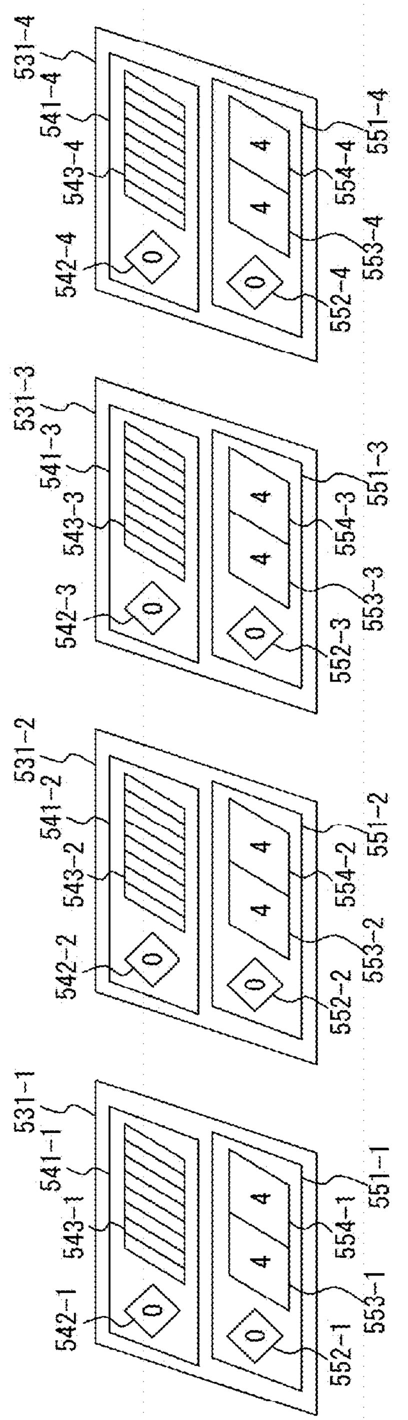
401-3-3
401-3-1
401-1-3
401-1-1
401-3-4
401-3-2
401-1-4
401-1-2
201-3
201-1
301
201-4
201-2
401-4-3
401-4-1
401-2-3
401-2-1
401-4-4
401-4-2
401-2-4
401-2-2

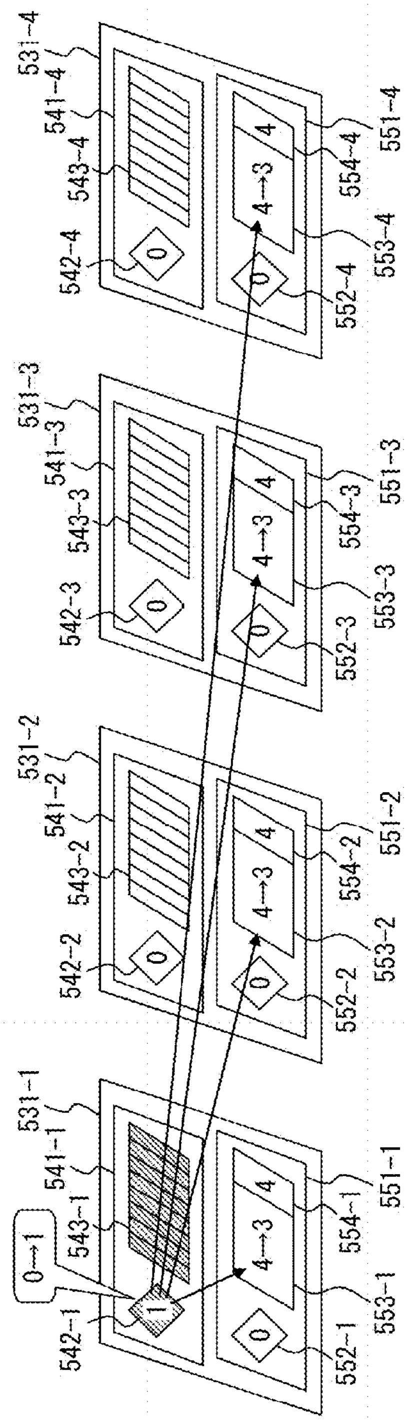
FIG. 2


501
511
521-1
521-2
521-3
521-4
CORE
CORE
CORE
CORE
522-1-1
522-2-1
522-3-1
522-4-1
THREAD
THREAD
THREAD
THREAD
THREAD
THREAD
THREAD
THREAD
522-1-2
522-2-2
522-3-2
522-4-2
542
0
541
543
531
552
553
0
NON-ARRIVAL COUNTER
EXPECTATION COUNTER
551
554

F I G. 3


531-4
541-4
543-4
542-4
551-4
554-4
553-4
552-4
531-3
541-3
543-3
542-3
551-3
554-3
553-3
552-3
531-2
541-2
543-2
542-2
551-2
554-2
553-2
552-2
531-1
541-1
543-1
542-1
551-1
554-1
553-1
552-1

F I G. 4 A



531-1
541-1
543-1
542-1
0→1
1
551-1
554-1
553-1
552-1
4→3
4
0
531-2
541-2
543-2
542-2
551-2
554-2
553-2
552-2
531-3
541-3
543-3
542-3
551-3
554-3
553-3
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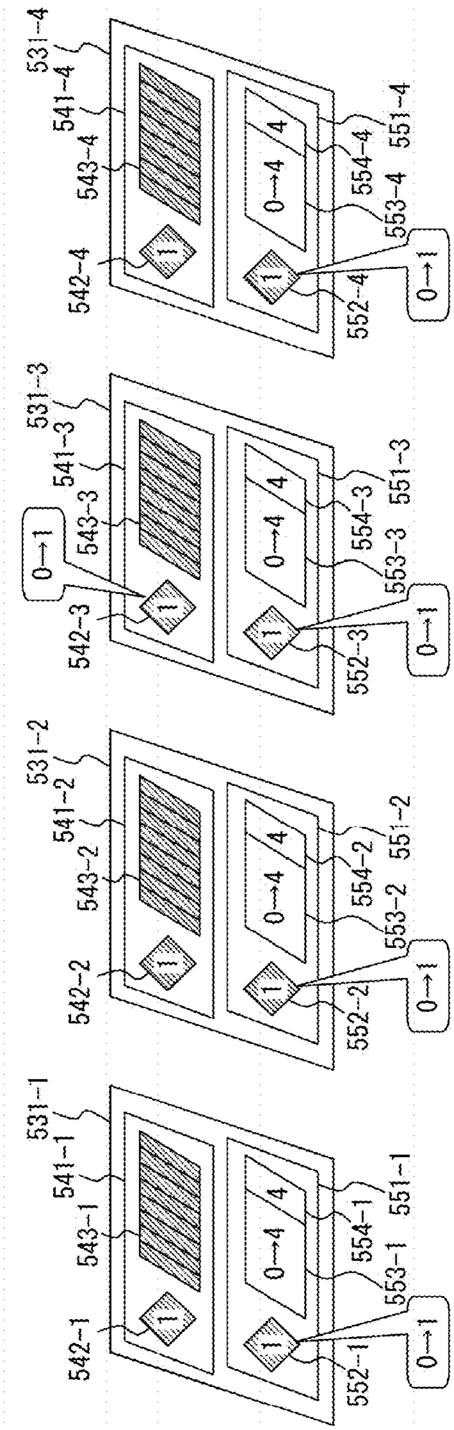
531-4
541-4
543-4
542-4
551-4
554-4
553-4
552-4

FIG. 4B


531-4
541-4
543-4
542-4
551-4
554-4
553-4
552-4
0→4
4
1
0→1
531-3
541-3
543-3
542-3
551-3
554-3
553-3
552-3
531-2
541-2
543-2
542-2
551-2
554-2
553-2
552-2
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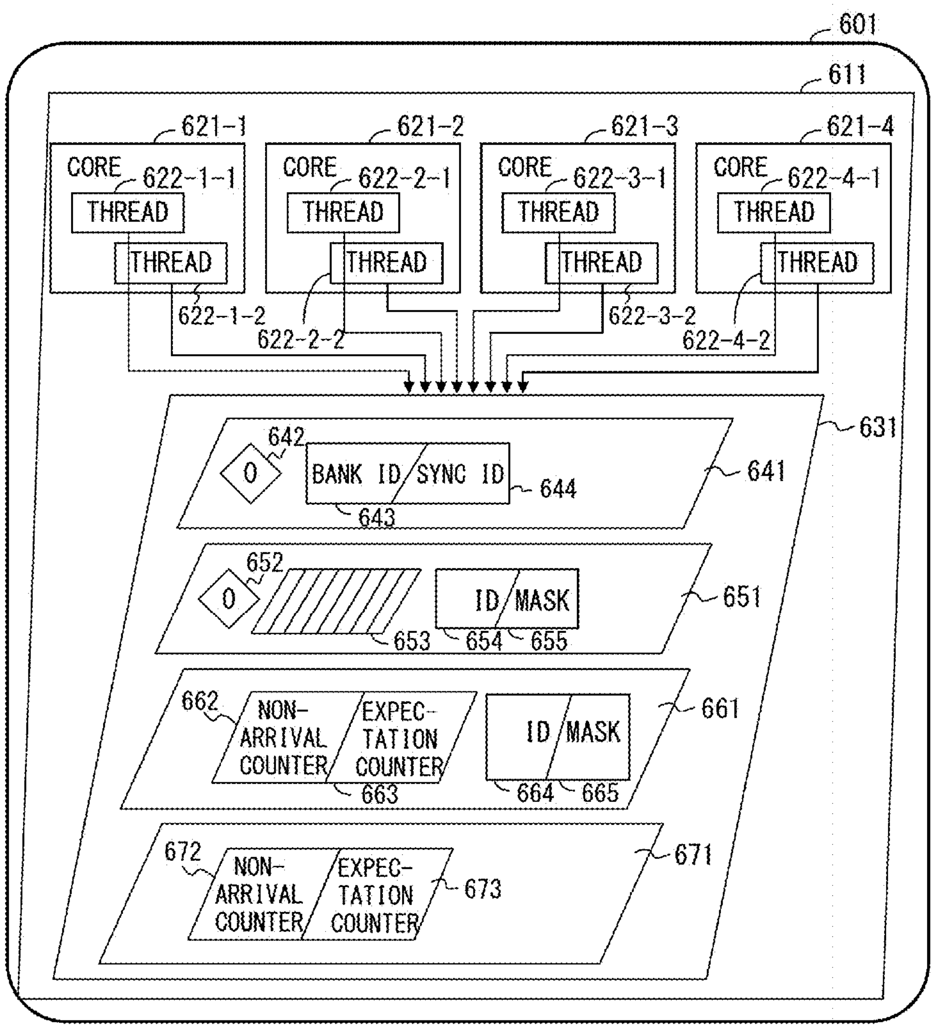
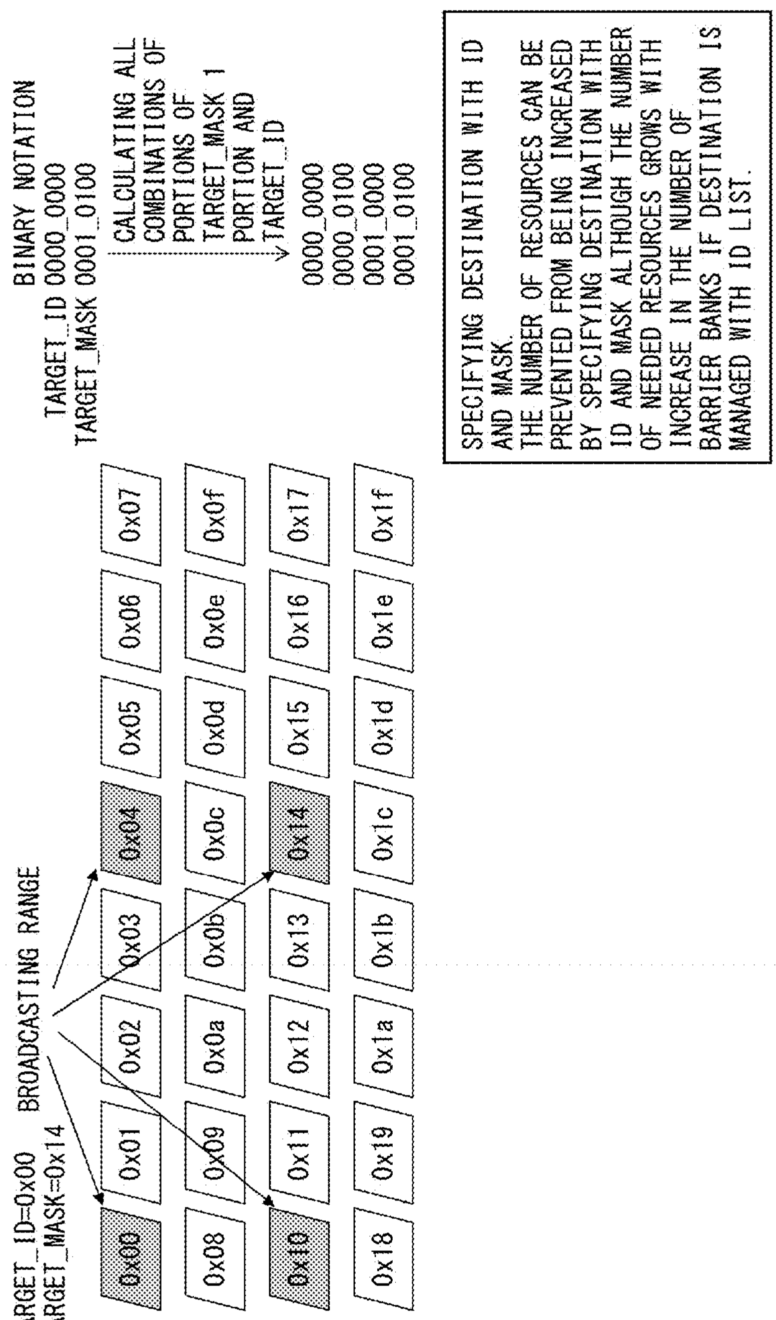
541-1
543-1
542-1
551-1
554-1
553-1
552-1

F I G. 4 C

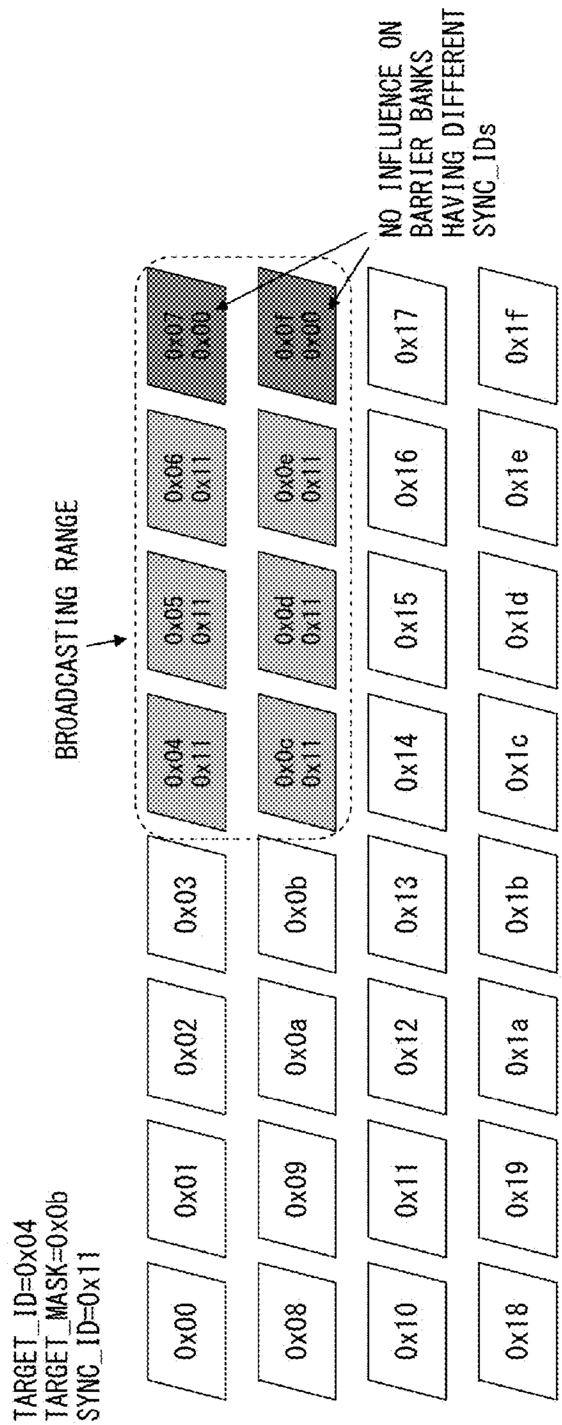

601
611
621-1
621-2
621-3
621-4
CORE
622-1-1
THREAD
THREAD
622-1-2
CORE
622-2-1
THREAD
THREAD
622-2-2
CORE
622-3-1
THREAD
THREAD
622-3-2
CORE
622-4-1
THREAD
THREAD
622-4-2
631
641
642
0
BANK ID
SYNC ID
643
644
651
652
0
ID
MASK
653
654
655
661
662
NON-ARRIVAL COUNTER
EXPEC-TATION COUNTER
663
ID
MASK
664
665
671
672
NON-ARRIVAL COUNTER
EXPEC-TATION COUNTER
673

F I G. 5



TARGET_ID=0x00
TARGET_MASK=0x14
BROADCASTING RANGE
0x00 0x01 0x02 0x03 0x04 0x05 0x06 0x07
0x08 0x09 0x0a 0x0b 0x0c 0x0d 0x0e 0x0f
0x10 0x11 0x12 0x13 0x14 0x15 0x16 0x17
0x18 0x19 0x1a 0x1b 0x1c 0x1d 0x1e 0x1f
BINARY NOTATION
TARGET_ID 0000_0000
TARGET_MASK 0001_0100
CALCULATING ALL COMBINATIONS OF PORTIONS OF TARGET_MASK 1 PORTION AND TARGET_ID
0000_0000
0000_0100
0001_0000
0001_0100
SPECIFYING DESTINATION WITH ID AND MASK.
THE NUMBER OF RESOURCES CAN BE PREVENTED FROM BEING INCREASED BY SPECIFYING DESTINATION WITH ID AND MASK ALTHOUGH THE NUMBER OF NEEDED RESOURCES GROWS WITH INCREASE IN THE NUMBER OF BARRIER BANKS IF DESTINATION IS MANAGED WITH ID LIST.

F I G. 6

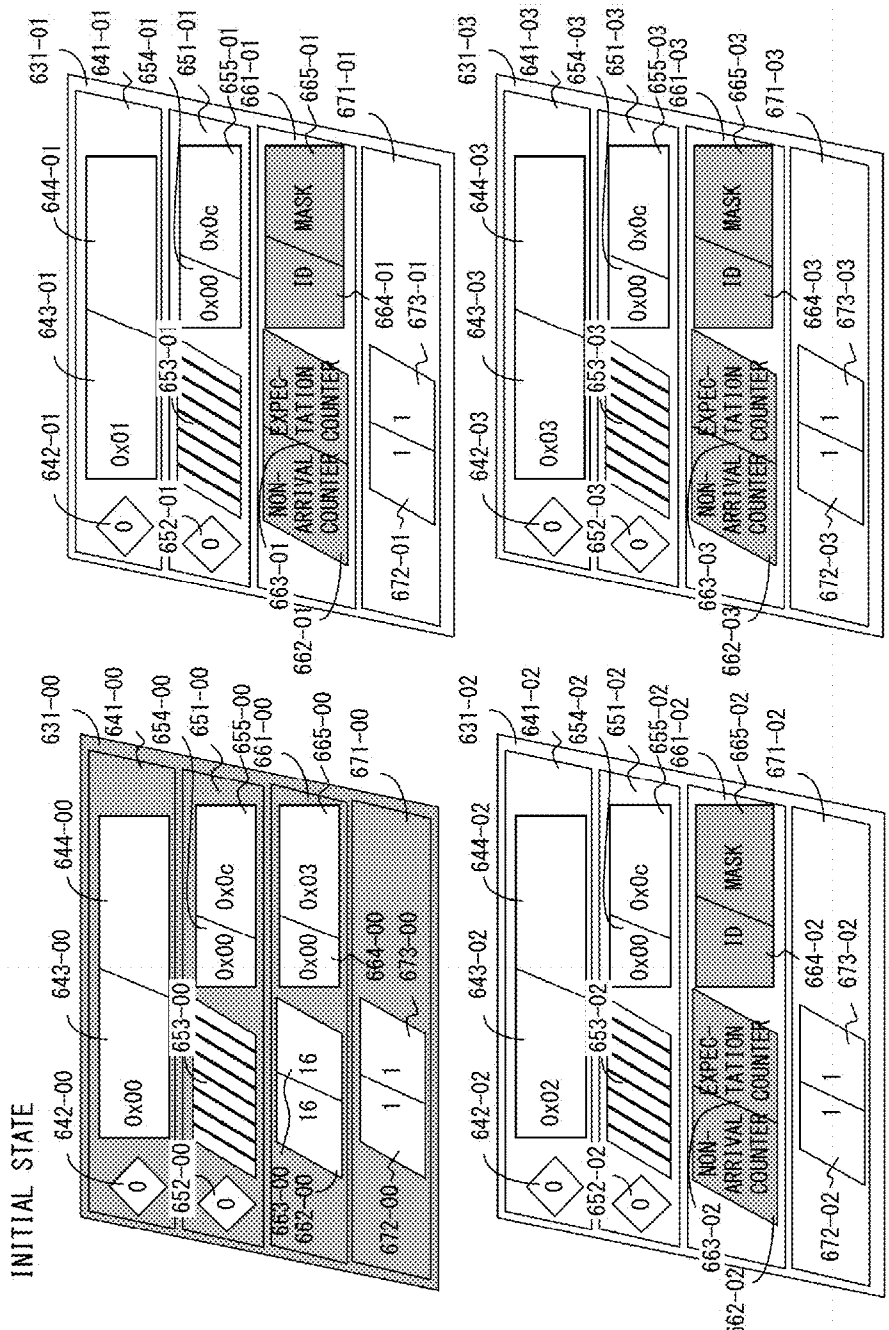

TARGET_ID=0x04
TARGET_MASK=0x0b
SYNC_ID=0x11
BROADCASTING RANGE
NO INFLUENCE ON BARRIER BANKS HAVING DIFFERENT SYNC_IDs
0x00
0x01
0x02
0x03
0x04 0x11
0x05 0x11
0x06 0x11
0x07 0x00
0x08
0x09
0x0a
0x0b
0x0c 0x11
0x0d 0x11
0x0e 0x11
0x0f 0x00
0x10
0x11
0x12
0x13
0x14
0x15
0x16
0x17
0x18
0x19
0x1a
0x1b
0x1c
0x1d
0x1e
0x1f

F I G. 7 A

```
              BINARY NOTATION
   TARGET_ID  0000_0100
 TARGET_MASK  0000_1011
                 |  CALCULATING ALL
                 |  COMBINATIONS OF
                 |  PORTIONS OF
                 |  TARGET_MASK 1 PORTION
                 ↓  AND TARGET_ID
              0000_0100
              0000_0101
              0000_0110
              0000_0111
              0000_1100
              0000_1101
              0000_1110
              0000_1111
```

SETTING SYNCID AS ADDITIONAL CONDITION IF DESTINATION IS SPECIFIED ONLY WITH ID AND MASK, THEY ARE APPLIED ONLY TO LIMITED RANGE CORRESPONDING TO 2^n NODES. ARBITRARY RANGE CAN BE SPECIFIED BY COMBINING WITH SYNCID.

FIG. 7B


INITIAL STATE
631-00
641-00
654-00
651-00
655-00
661-00
665-00
671-00
644-00
643-00
642-00
0x00
0x00
0x0c
0x00
0x03
16
16
1
1
653-00
652-00
663-00
662-00
664-00
673-00
672-00
631-01
641-01
654-01
651-01
655-01
661-01
665-01
671-01
644-01
643-01
642-01
0x01
0x00
0x0c
ID
MASK
NON-ARRIVAL COUNTER
EXPEC-TATION COUNTER
653-01
652-01
663-01
662-01
664-01
673-01
672-01
631-02
641-02
654-02
651-02
655-02
661-02
665-02
671-02
644-02
643-02
642-02
0x02
653-02
652-02
663-02
662-02
664-02
673-02
672-02
631-03
641-03
654-03
651-03
655-03
661-03
665-03
671-03
644-03
643-03
642-03
0x03
653-03
652-03
663-03
662-03
664-03
673-03
672-03

F I G. 8 A

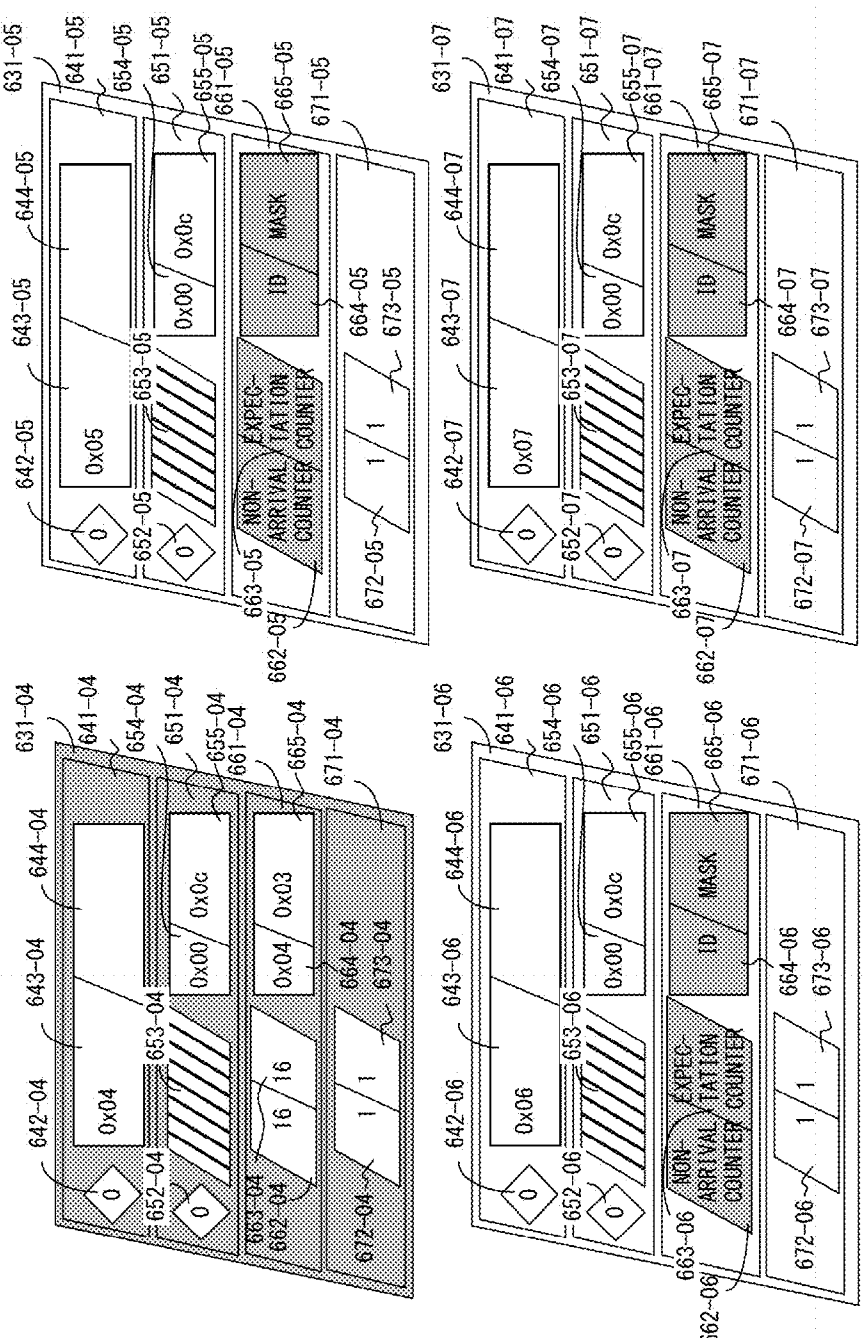
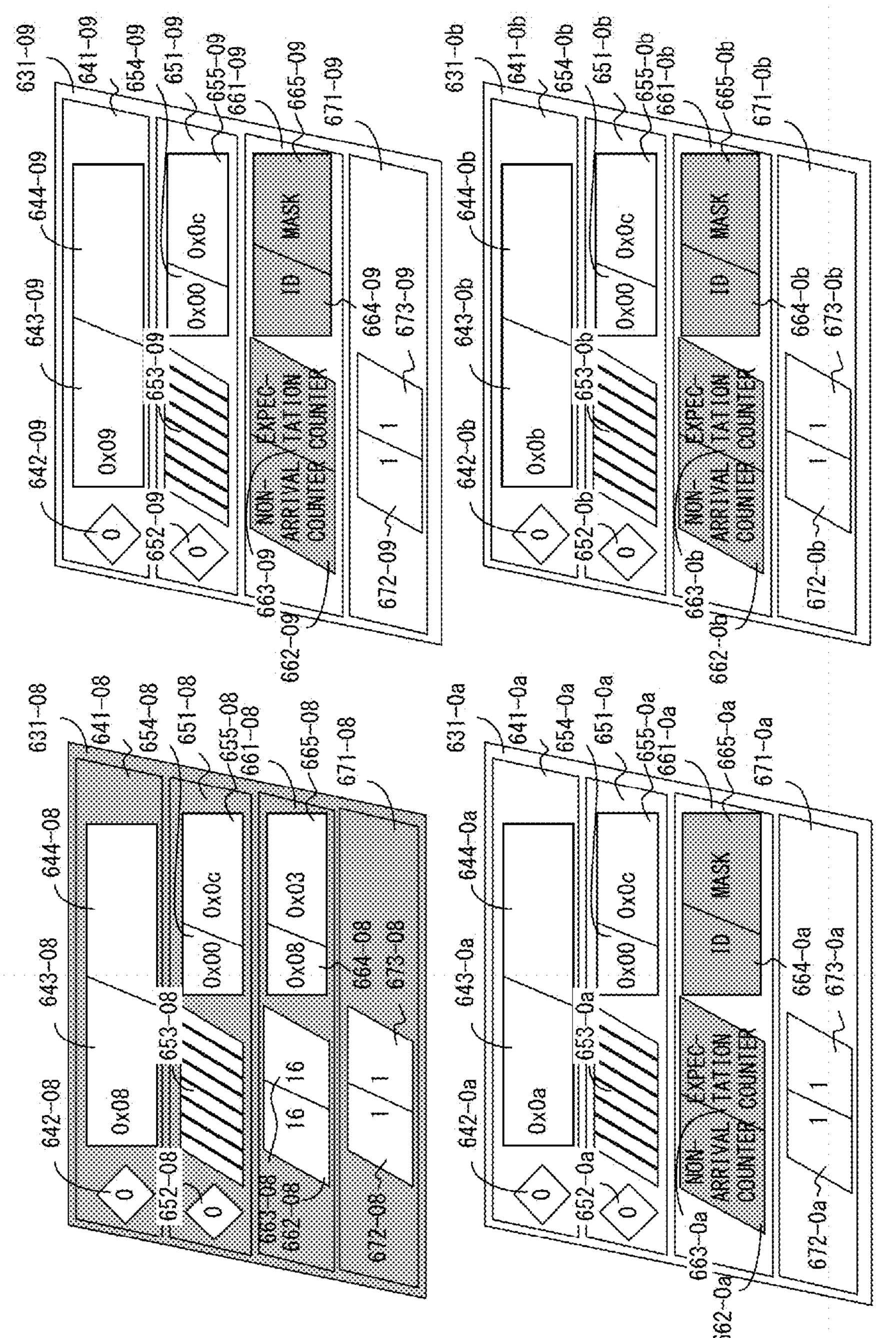

0x04
0x00
0x0c
0x04
0x03
16
0x05
NON-ARRIVAL COUNTER
EXPEC-TATION COUNTER
ID
MASK
0x06
0x07

FIG. 8B


631-09
641-09
654-09
651-09
655-09
661-09
665-09
671-09
644-09
643-09
642-09
652-09
653-09
0x09
0
0x00
0x0c
ID
MASK
NON-ARRIVAL COUNTER
EXPECTATION COUNTER
1
1
663-09
662-09
664-09
673-09
672-09
631-0b
641-0b
654-0b
651-0b
655-0b
661-0b
665-0b
671-0b
644-0b
643-0b
642-0b
652-0b
653-0b
0x0b
663-0b
662-0b
664-0b
673-0b
672-0b
631-08
641-08
654-08
651-08
655-08
661-08
665-08
671-08
644-08
643-08
642-08
652-08
653-08
0x08
0x03
16
663-08
662-08
664-08
673-08
672-08
631-0a
641-0a
654-0a
651-0a
655-0a
661-0a
665-0a
671-0a
644-0a
643-0a
642-0a
652-0a
653-0a
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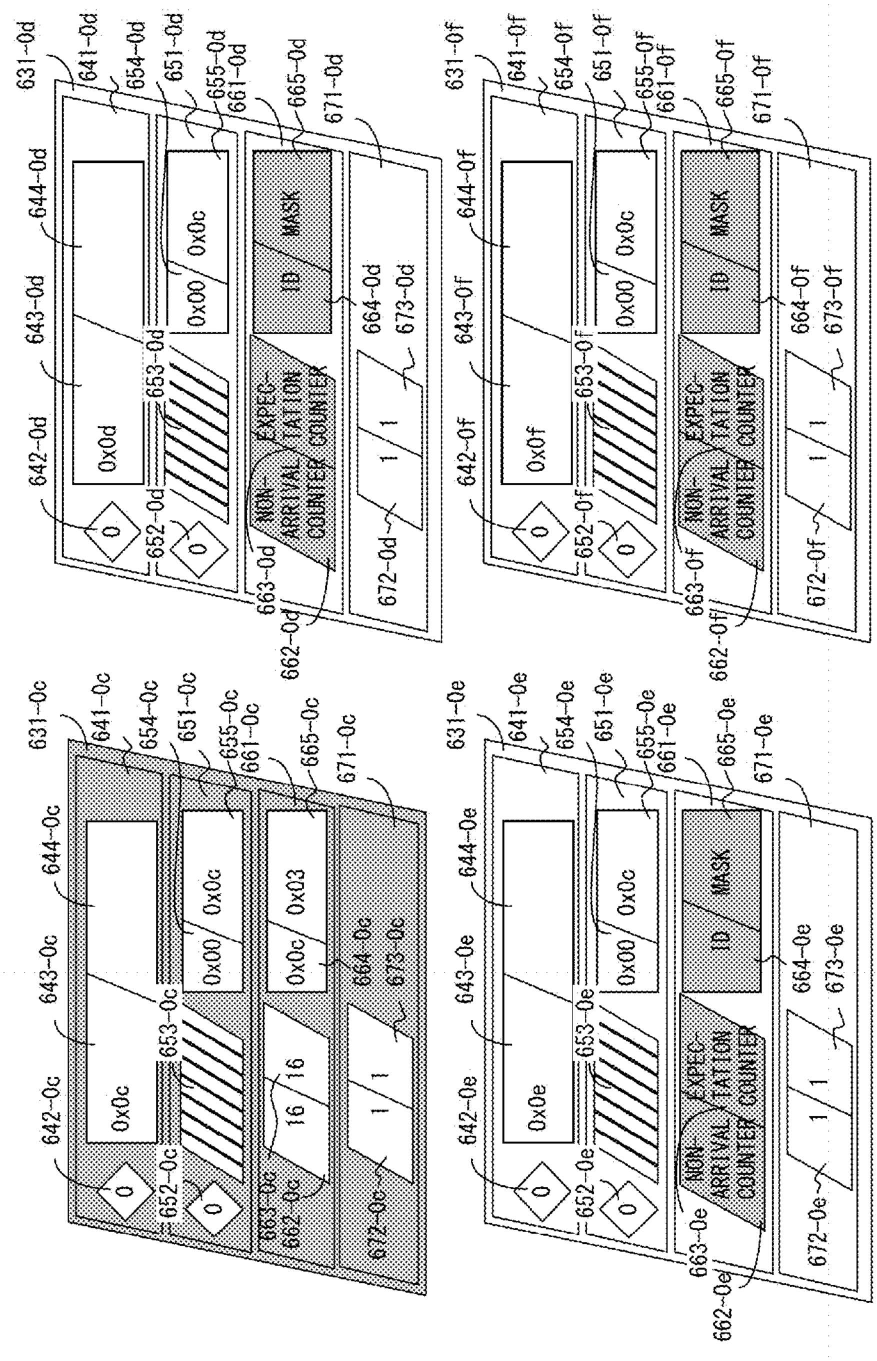
663-0a
662-0a
664-0a
673-0a
672-0a

FIG. 8C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641-0d
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651-0d
655-0d
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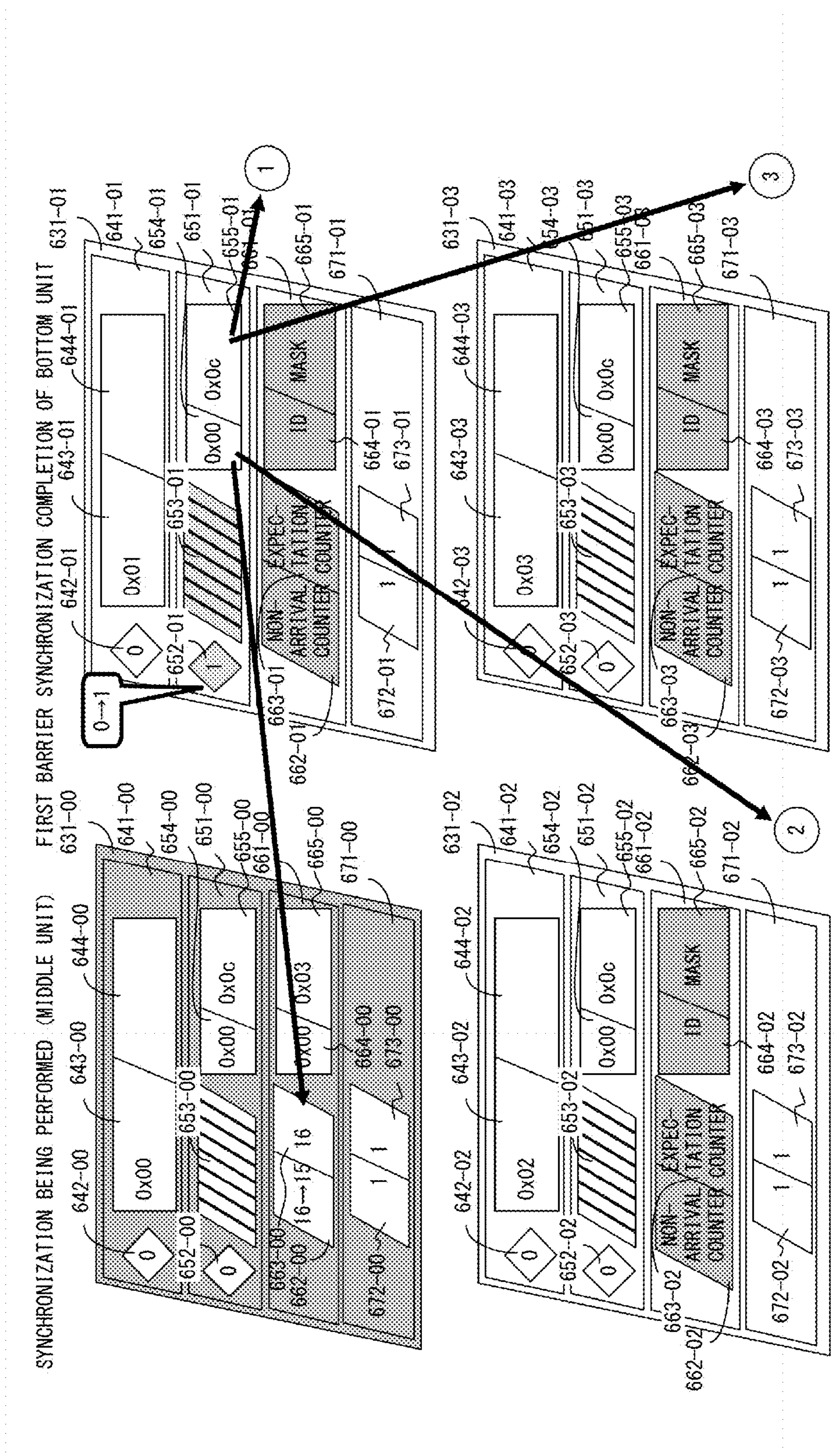
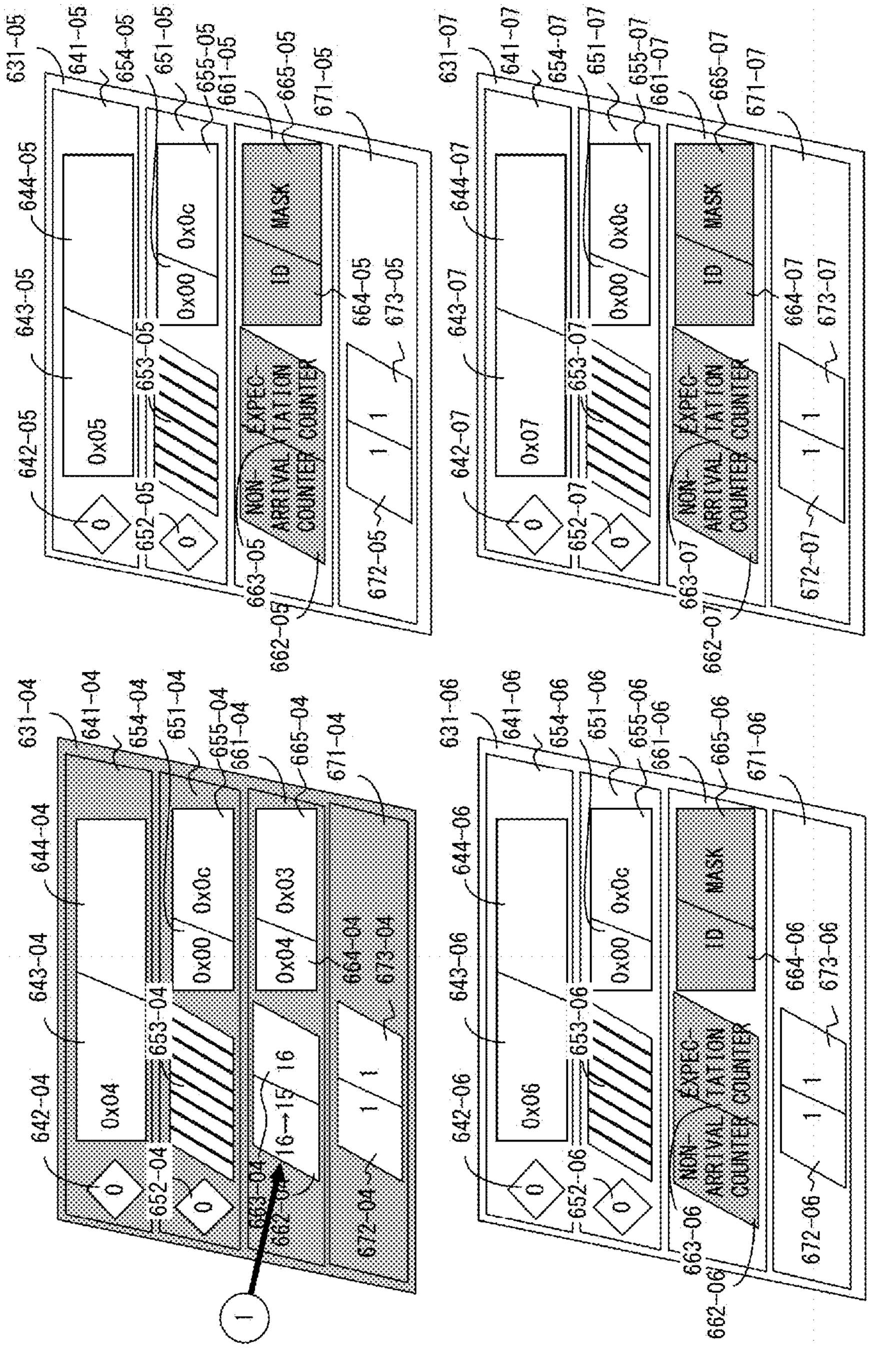
665-0d
671-0d
644-0d
643-0d
642-0d
653-0d
652-0d
663-0d
662-0d
664-0d
673-0d
672-0d
0x0d
0x00
0x0c
ID
MASK
NON-ARRIVAL COUNTER
EXPECTATION COUNTER
1
1
0
0
631-0f
641-0f
654-0f
651-0f
655-0f
661-0f
665-0f
671-0f
644-0f
643-0f
642-0f
653-0f
652-0f
663-0f
662-0f
664-0f
673-0f
672-0f
0x0f
0x00
0x0c
ID
MASK
NON-ARRIVAL COUNTER
EXPECTATION COUNTER
1
1
0
0
631-0c
641-0c
654-0c
651-0c
655-0c
661-0c
665-0c
671-0c
644-0c
643-0c
642-0c
653-0c
652-0c
663-0c
662-0c
664-0c
673-0c
672-0c
0x0c
0x00
0x0c
0x0c
0x03
16
16
1
1
0
0
631-0e
641-0e
654-0e
651-0e
655-0e
661-0e
665-0e
671-0e
644-0e
643-0e
642-0e
653-0e
652-0e
663-0e
662-0e
664-0e
673-0e
672-0e
0x0e
0x00
0x0c
ID
MASK
NON-ARRIVAL COUNTER
EXPECTATION COUNTER
1
1
0
0

FIG. 8D



SYNCHRONIZATION BEING PERFORMED (MIDDLE UNIT)
FIRST BARRIER SYNCHRONIZATION COMPLETION OF BOTTOM UNIT
0→1
16→15
NON-ARRIVAL COUNTER
EXPECTATION COUNTER
ID
MASK
0x00
0x01
0x02
0x03
0x0c

FIG. 9A


631-04
641-04
654-04
651-04
655-04
661-04
665-04
671-04
642-04
643-04
644-04
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0x00
0x0c
0x03
16→15
16
1
1
652-04
653-04
662-04
663-04
664-04
672-04
673-04
631-05
641-05
654-05
651-05
655-05
661-05
665-05
671-05
642-05
643-05
644-05
0x05
ID
MASK
NON-ARRIVAL COUNTER
EXPECTATION COUNTER
652-05
653-05
662-05
663-05
664-05
672-05
673-05
631-06
641-06
654-06
651-06
655-06
661-06
665-06
671-06
642-06
643-06
644-06
0x06
652-06
653-06
662-06
663-06
664-06
672-06
673-06
631-07
641-07
654-07
651-07
655-07
661-07
665-07
671-07
642-07
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653-07
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664-07
672-07
673-07

F I G. 9 B

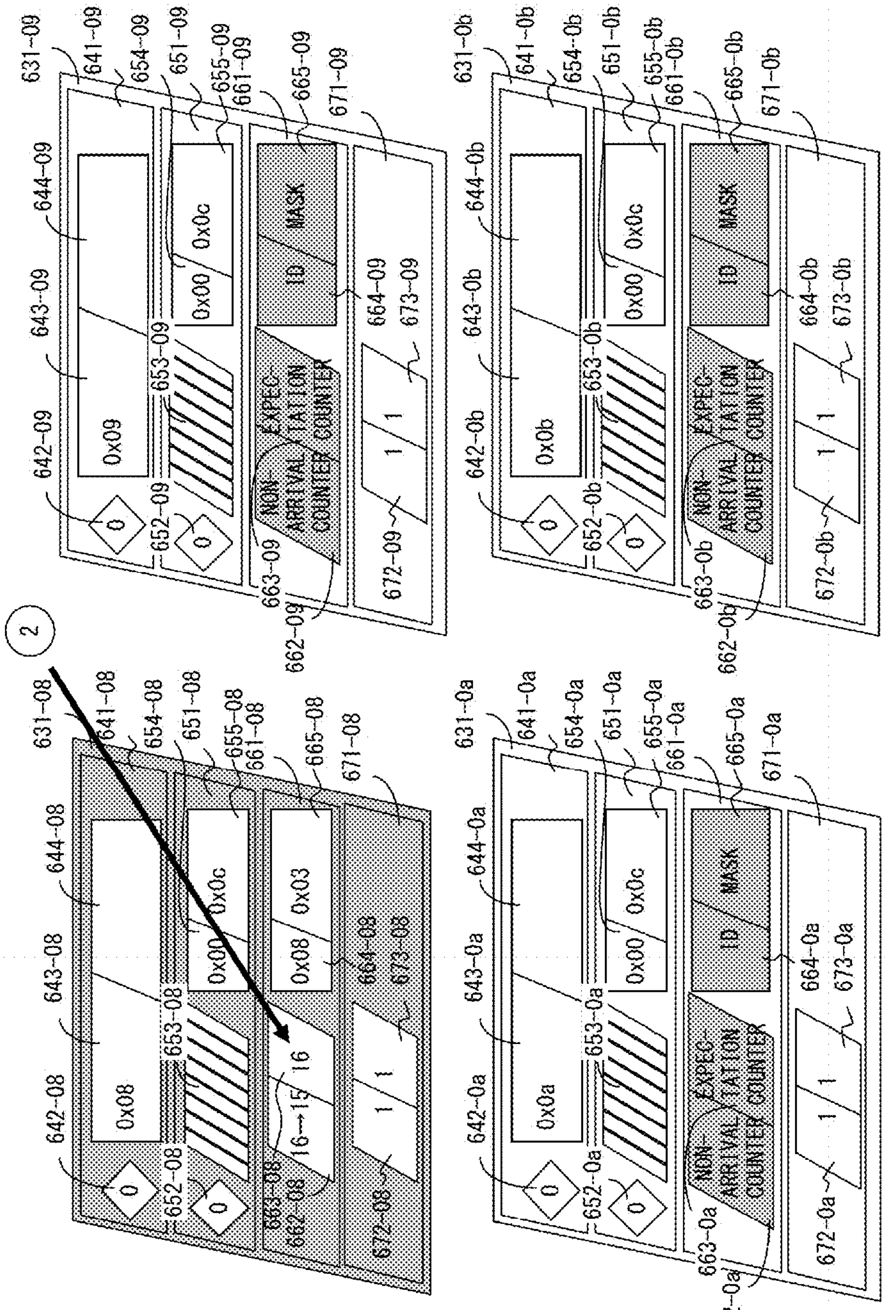
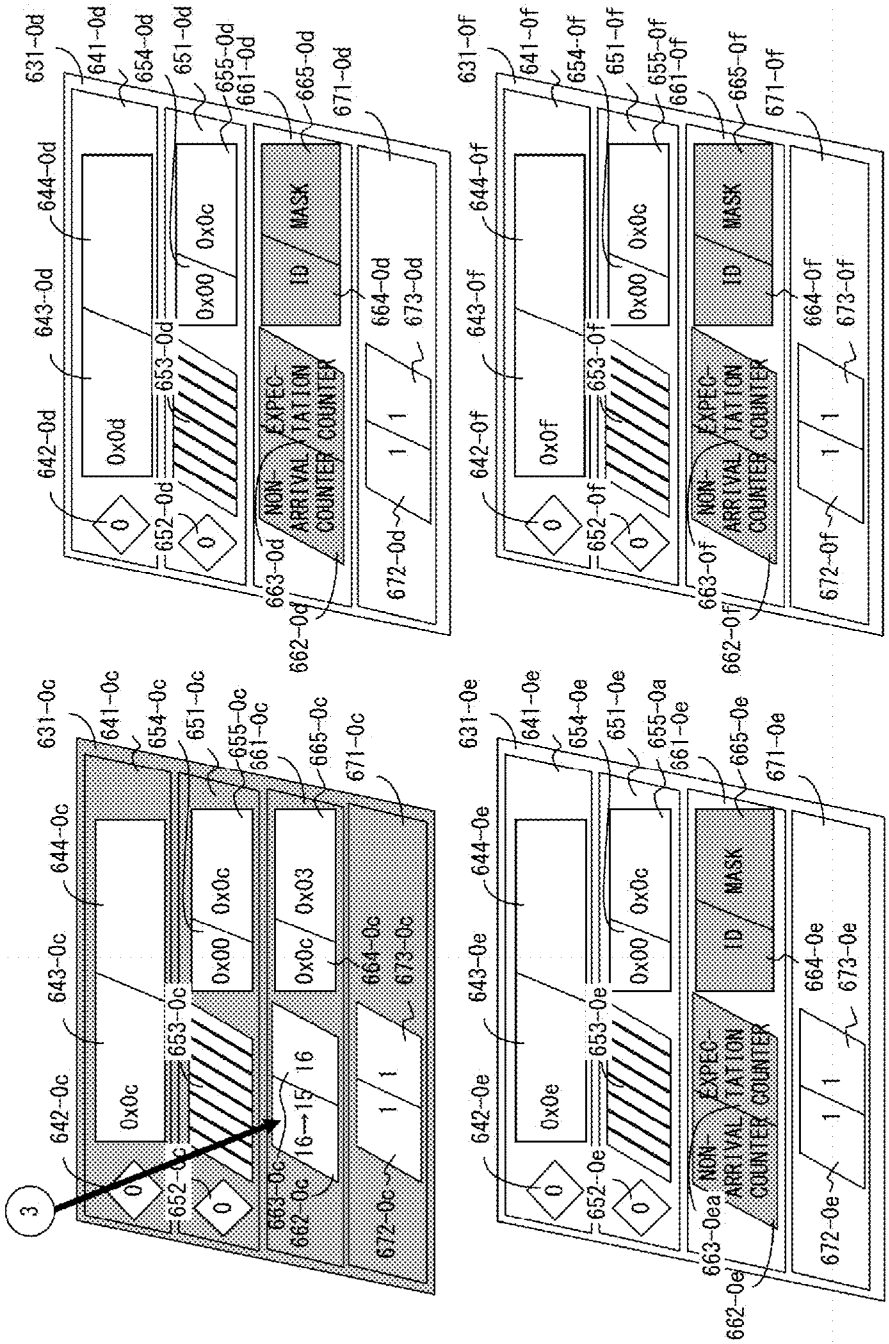

2
0x08
0x00
0x0c
0x08
0x03
16→15
16
1
1
0x09
0x0b
0x0a
ID
MASK
NON-ARRIVAL COUNTER
EXPECTATION COUNTER
0

FIG. 9C



631-0d
641-0d
654-0d
651-0d
655-0d
661-0d
665-0d
671-0d
644-0d
643-0d
642-0d
653-0d
652-0d
0x0d
0x00
0x0c
ID
MASK
NON-ARRIVAL COUNTER
EXPECTATION COUNTER
664-0d
673-0d
672-0d
663-0d
662-0d
631-0f
641-0f
654-0f
651-0f
655-0f
661-0f
665-0f
671-0f
644-0f
643-0f
642-0f
653-0f
652-0f
0x0f
664-0f
673-0f
672-0f
663-0f
662-0f
631-0c
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654-0c
651-0c
655-0c
661-0c
665-0c
671-0c
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643-0c
642-0c
653-0c
652-0c
0x0c
0x03
16→15
16
664-0c
673-0c
672-0c
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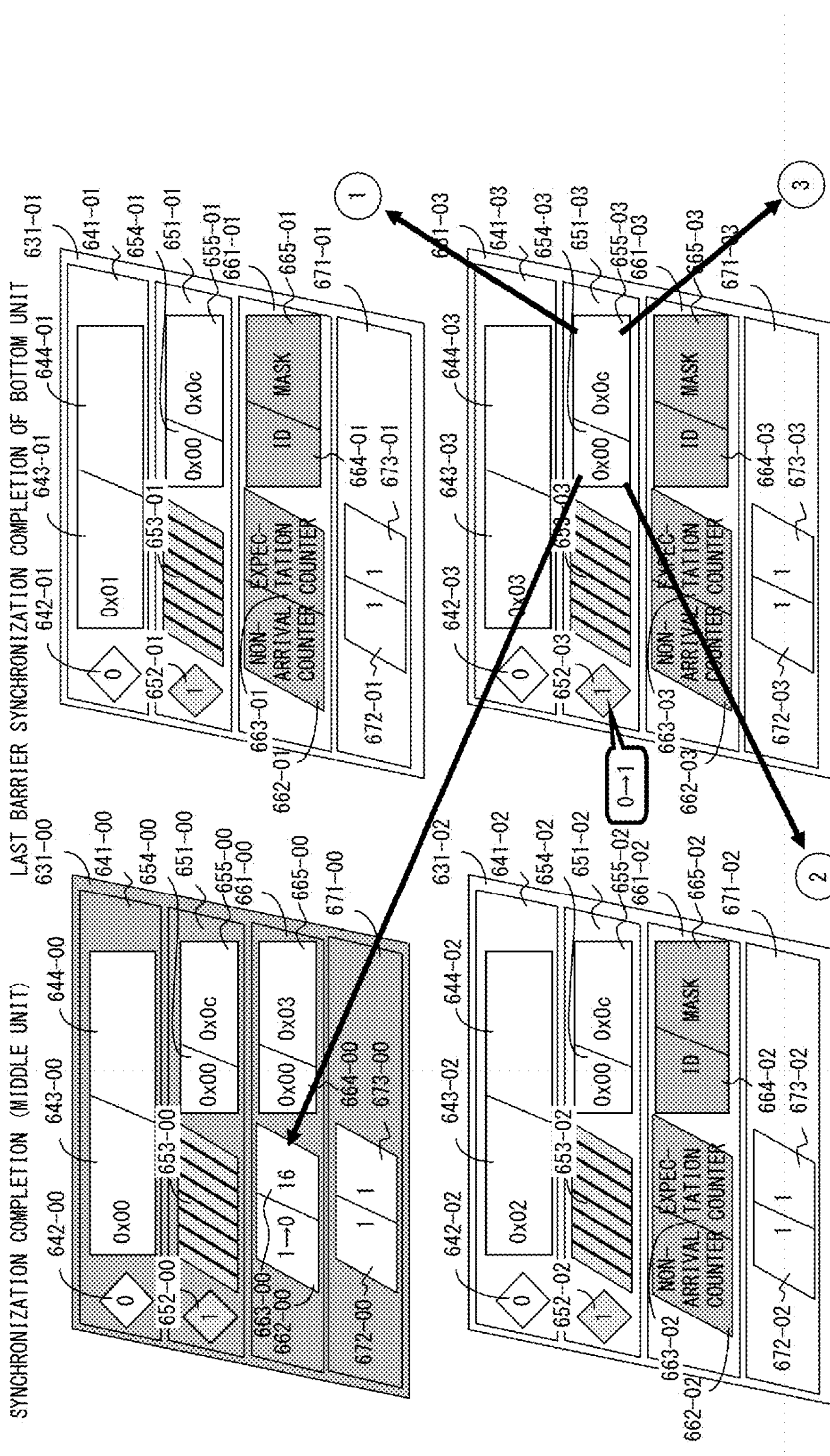
662-0e

FIG. 9D


SYNCHRONIZATION COMPLETION (MIDDLE UNIT)
LAST BARRIER SYNCHRONIZATION COMPLETION OF BOTTOM UNIT
631-00
641-00
654-00
651-00
655-00
661-00
665-00
671-00
644-00
643-00
642-00
653-00
652-00
663-00
662-00
664-00
673-00
672-00
0x00
0x0c
0x03
16
1→0
1 / 1
631-01
641-01
654-01
651-01
655-01
661-01
665-01
671-01
644-01
643-01
642-01
653-01
652-01
663-01
662-01
664-01
673-01
672-01
0x01
ID
MASK
NON-ARRIVAL COUNTER
EXPECTATION COUNTER
631-02
641-02
642-02
643-02
644-02
0x02
631-03
0x03
0→1
1
2
3

F I G. 1 0 A

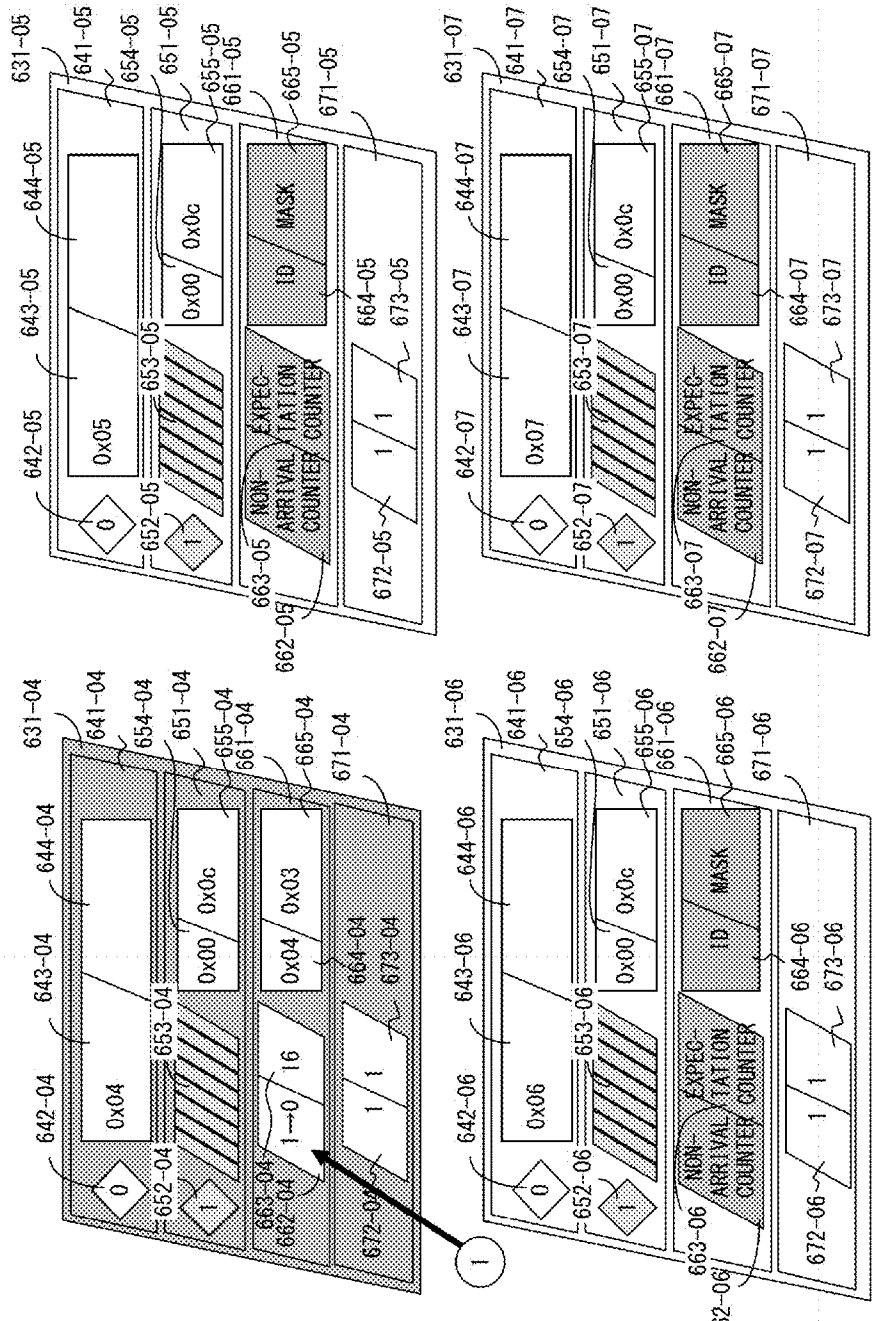
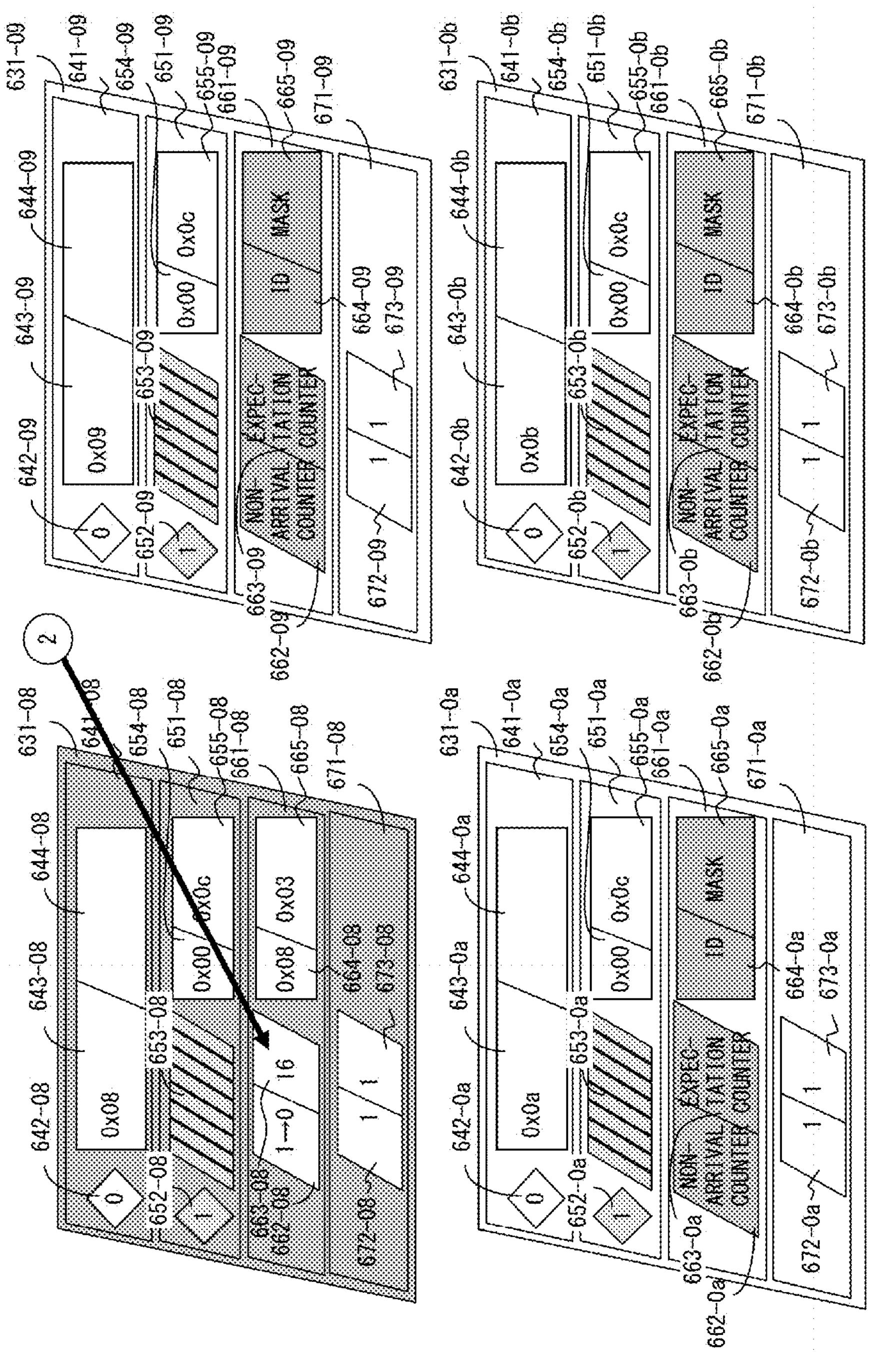

631-04
641-04
654-04
651-04
655-04
661-04
665-04
671-04
644-04
643-04
642-04
0x04
653-04
0x00
0x0c
0x04
0x03
664-04
673-04
1→0
16
1
1
652-04
663-04
662-04
672-04
0
1
631-05
641-05
654-05
651-05
655-05
661-05
665-05
671-05
644-05
643-05
642-05
0x05
653-05
0x00
0x0c
ID
MASK
664-05
673-05
NON-ARRIVAL COUNTER
EXPECTATION COUNTER
652-05
663-05
662-05
672-05
631-06
641-06
654-06
651-06
655-06
661-06
665-06
671-06
644-06
643-06
642-06
0x06
653-06
664-06
673-06
652-06
663-06
662-06
672-06
631-07
641-07
654-07
651-07
655-07
661-07
665-07
671-07
644-07
643-07
642-07
0x07
653-07
664-07
673-07
652-07
663-07
662-07
672-07

FIG. 10B



0x08
0x09
0x0a
0x0b
0x00
0x0c
0x03
16
1→0
1 1
ID
MASK
NON-ARRIVAL COUNTER
EXPECTATION COUNTER

FIG. 10C

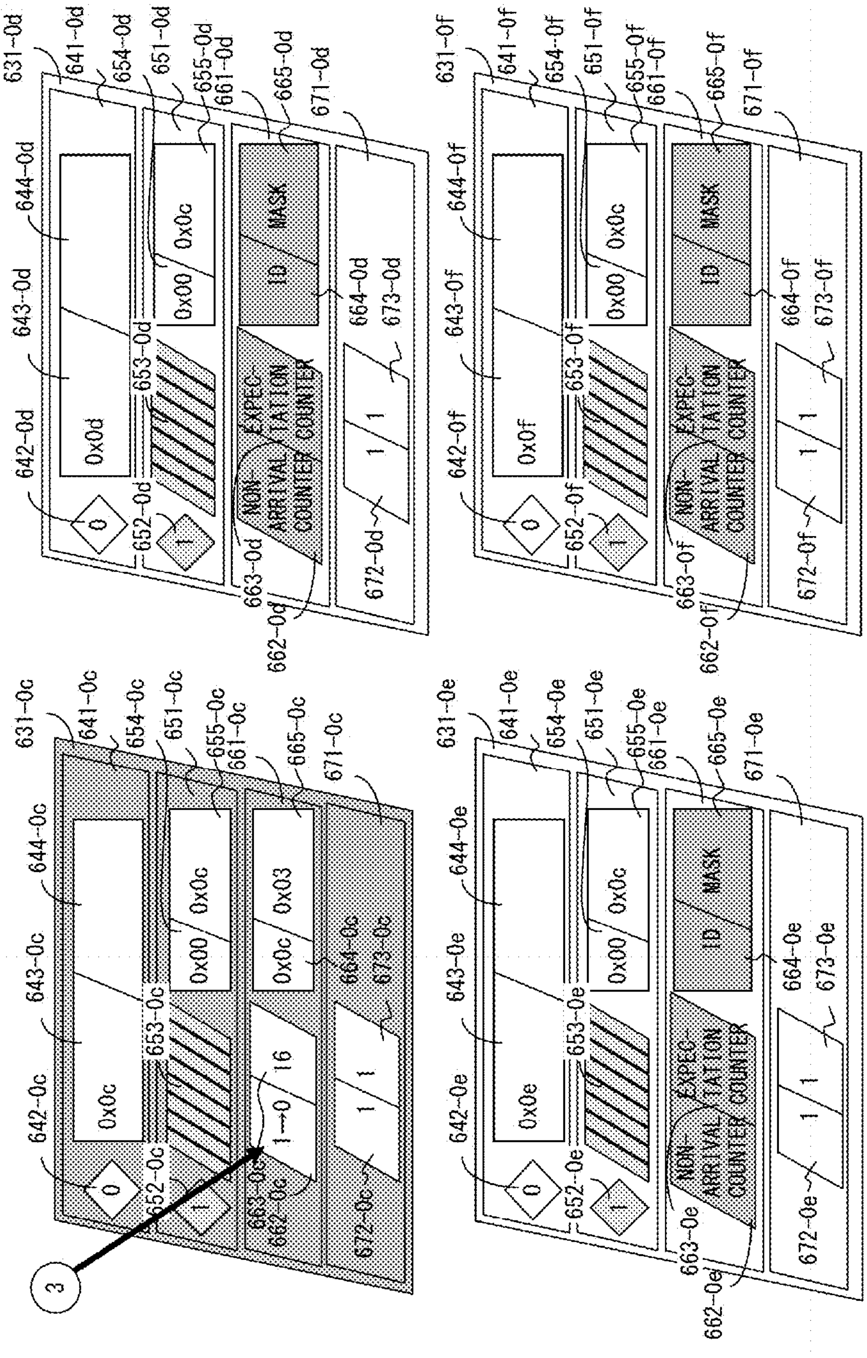
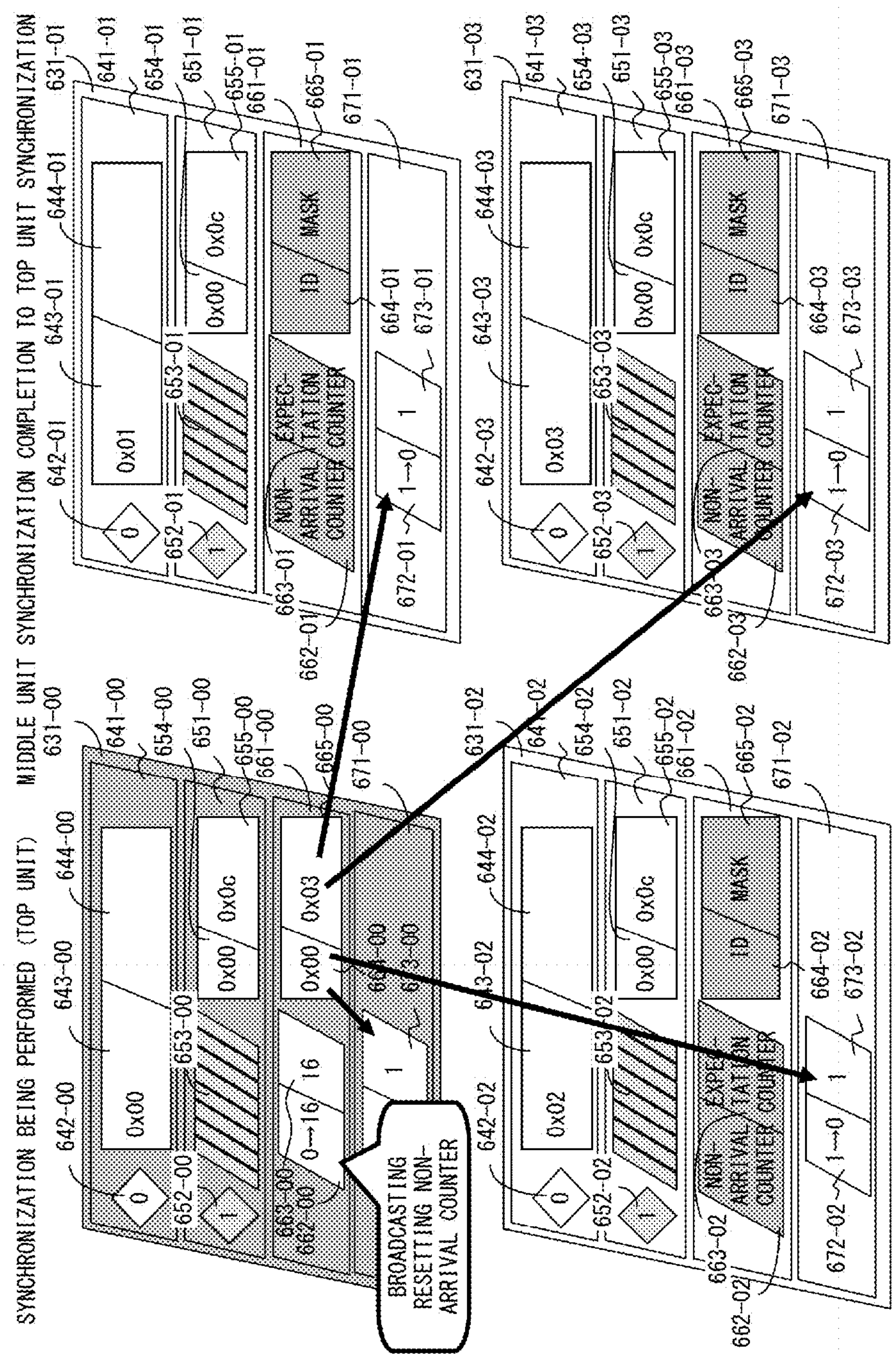

631-0c
641-0c
654-0c
651-0c
655-0c
661-0c
665-0c
671-0c
644-0c
643-0c
642-0c
653-0c
652-0c
663-0c
662-0c
664-0c
673-0c
672-0c
0
1
0x0c
0x00
0x0c
1→0
16
0x0c
0x03
1
1
3
631-0d
641-0d
654-0d
651-0d
655-0d
661-0d
665-0d
671-0d
644-0d
643-0d
642-0d
653-0d
652-0d
663-0d
662-0d
664-0d
673-0d
672-0d
0x0d
0x00
0x0c
NON-ARRIVAL COUNTER
EXPECTATION COUNTER
ID
MASK
631-0e
641-0e
654-0e
651-0e
655-0e
661-0e
665-0e
671-0e
644-0e
643-0e
642-0e
653-0e
652-0e
663-0e
662-0e
664-0e
673-0e
672-0e
0x0e
631-0f
641-0f
654-0f
651-0f
655-0f
661-0f
665-0f
671-0f
644-0f
643-0f
642-0f
653-0f
652-0f
663-0f
662-0f
664-0f
673-0f
672-0f
0x0f

FIG. 10D


SYNCHRONIZATION BEING PERFORMED (TOP UNIT)
MIDDLE UNIT SYNCHRONIZATION COMPLETION TO TOP UNIT SYNCHRONIZATION
BROADCASTING RESETTING NON-ARRIVAL COUNTER
NON-ARRIVAL COUNTER
EXPECTATION COUNTER
ID
MASK
0x00
0x01
0x02
0x03
0x0c
0→16
16
1→0
1
0
631-00
641-00
642-00
643-00
644-00
651-00
652-00
653-00
654-00
655-00
661-00
662-00
663-00
665-00
671-00
631-01
641-01
642-01
643-01
644-01
651-01
652-01
653-01
654-01
655-01
661-01
662-01
663-01
664-01
665-01
671-01
672-01
673-01
631-02
641-02
642-02
643-02
644-02
651-02
652-02
653-02
654-02
655-02
661-02
662-02
663-02
664-02
665-02
671-02
672-02
673-02
631-03
641-03
642-03
643-03
644-03
651-03
652-03
653-03
654-03
655-03
661-03
662-03
663-03
664-03
665-03
671-03
672-03
673-03

F I G. 1 1 A

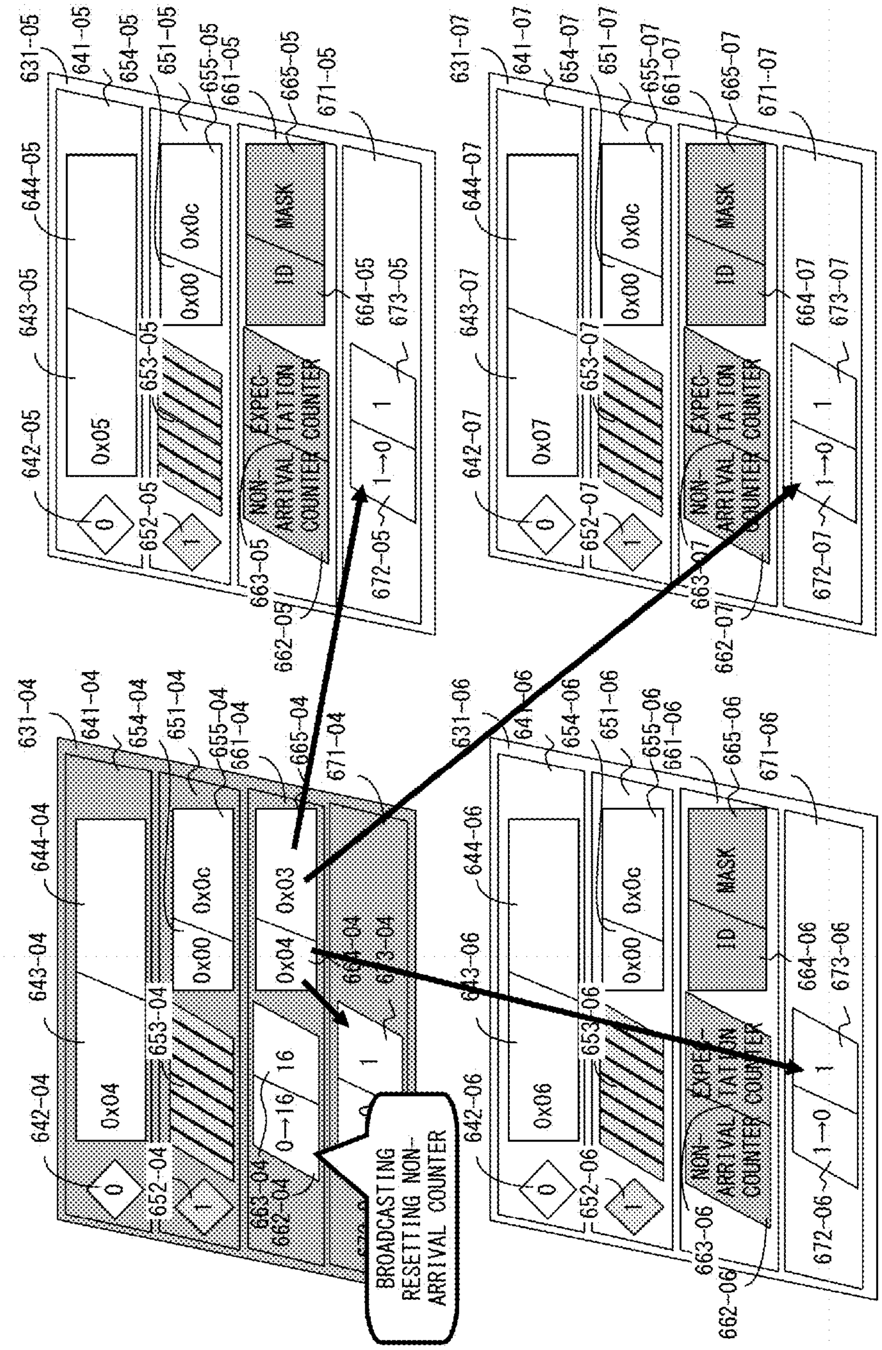
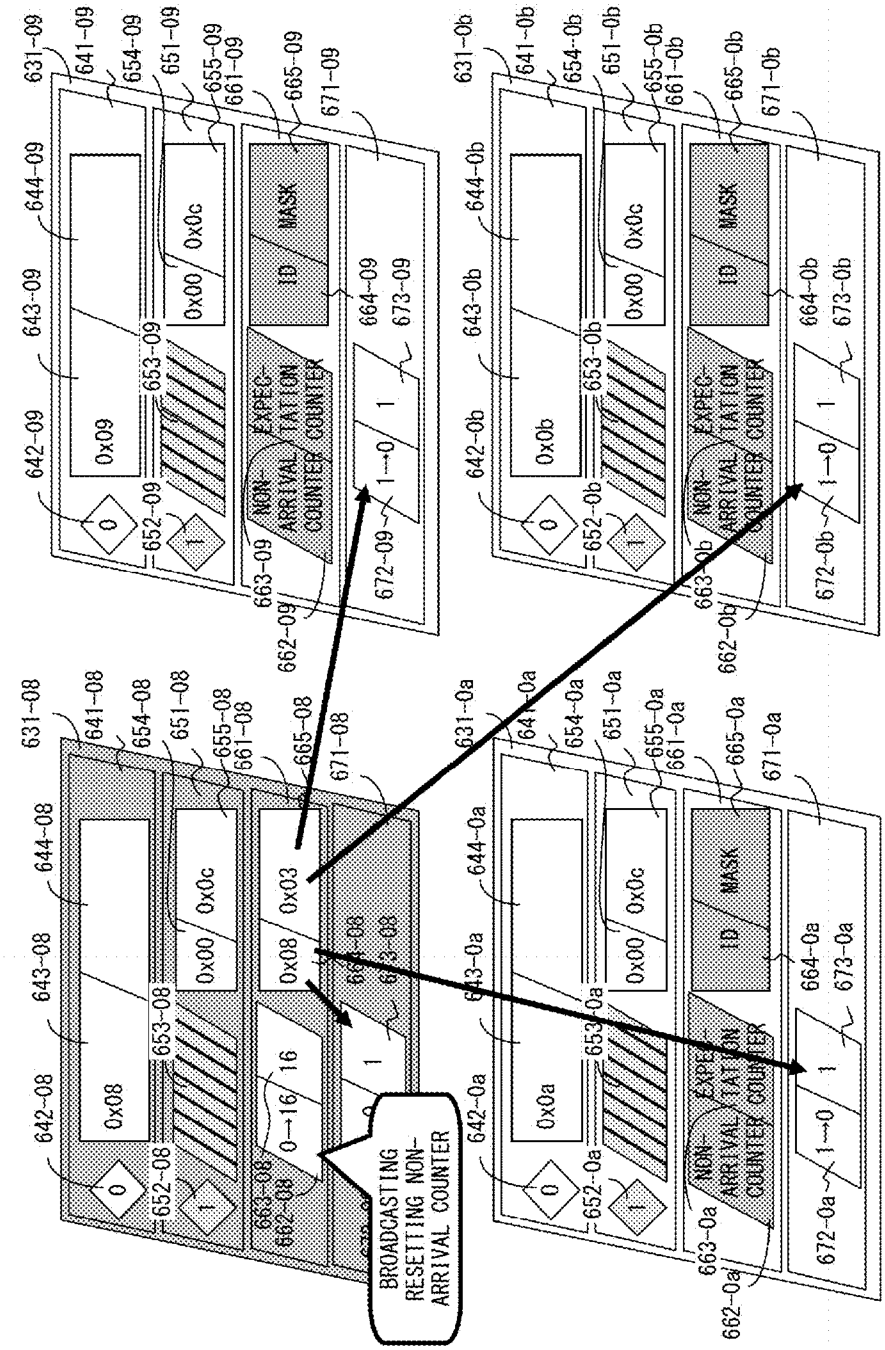
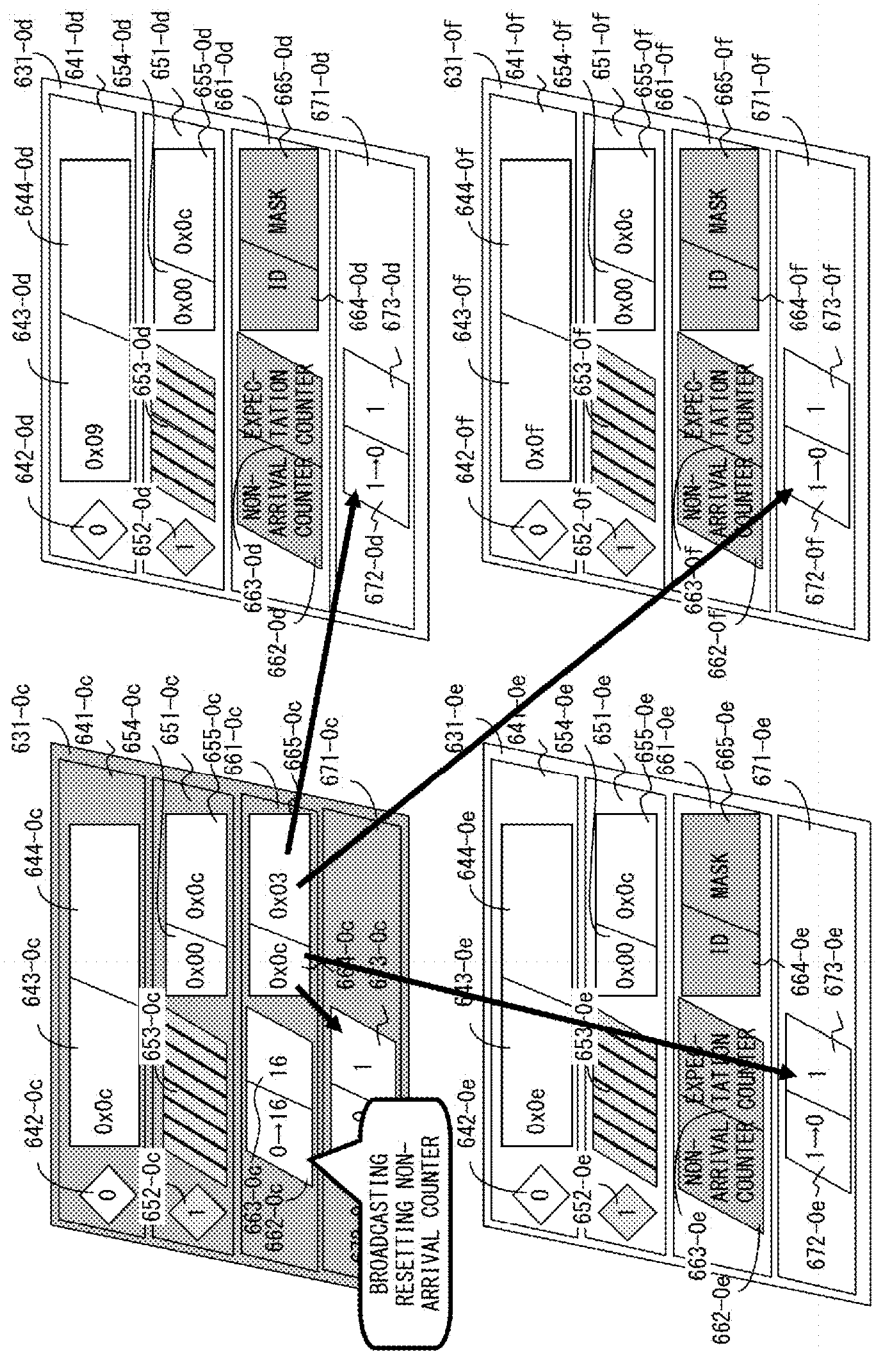

631-04
641-04
654-04
651-04
655-04
661-04
665-04
671-04
642-04
643-04
644-04
0x04
0
653-04
652-04
1
0x00
0x0c
0x04
0x03
0→16
16
1
663-04
662-04
664-04
673-04
BROADCASTING RESETTING NON-ARRIVAL COUNTER
631-05
641-05
654-05
651-05
655-05
661-05
665-05
671-05
642-05
643-05
644-05
0x05
0
653-05
652-05
1
0x00
0x0c
ID
MASK
NON-ARRIVAL COUNTER
EXPEC-TATION COUNTER
663-05
662-05
664-05
673-05
1→0
1
672-05
631-06
641-06
654-06
651-06
655-06
661-06
665-06
671-06
642-06
643-06
644-06
0x06
0
653-06
652-06
1
0x00
0x0c
ID
MASK
NON-ARRIVAL COUNTER
EXPEC-TATION COUNTER
663-06
662-06
664-06
673-06
1→0
1
672-06
631-07
641-07
654-07
651-07
655-07
661-07
665-07
671-07
642-07
643-07
644-07
0x07
0
653-07
652-07
1
0x00
0x0c
ID
MASK
NON-ARRIVAL COUNTER
EXPEC-TATION COUNTER
663-07
662-07
664-07
673-07
1→0
1
672-07

FIG. 11B

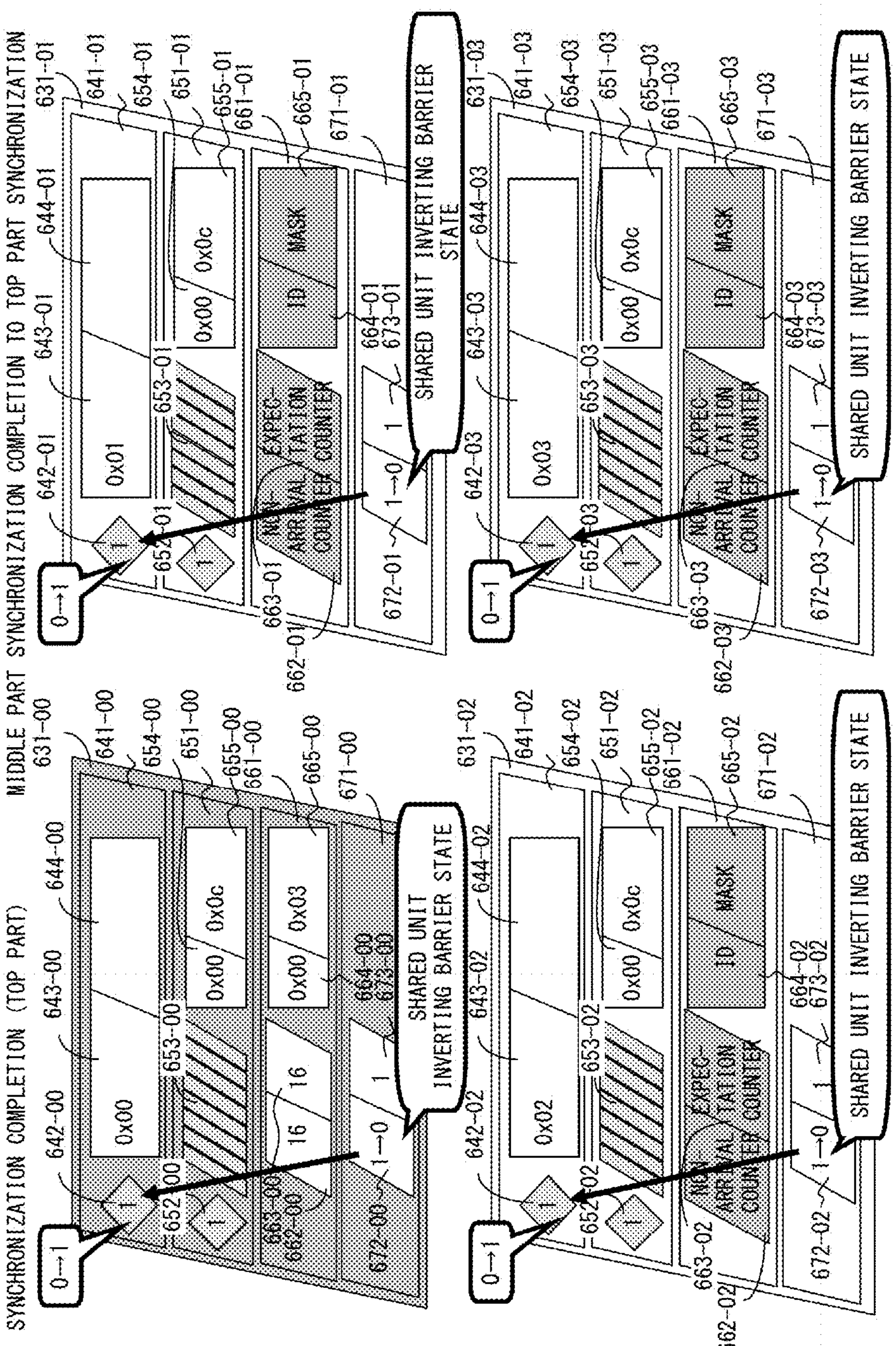


0x08
0x00
0x0c
0x03
0→16
16
1
0x09
0x0a
0x0b
ID
MASK
NON-ARRIVAL COUNTER
EXPECTATION COUNTER
1→0
BROADCASTING RESETTING NON-ARRIVAL COUNTER
631-08
631-09
631-0a
631-0b

FIG. 11C


631-0d
641-0d
654-0d
651-0d
655-0d
661-0d
665-0d
671-0d
644-0d
643-0d
642-0d
0x09
0x00
0x0c
653-0d
652-0d
NON-ARRIVAL COUNTER
EXPECTATION COUNTER
ID
MASK
664-0d
673-0d
663-0d
662-0d
672-0d
1→0
1
631-0c
641-0c
654-0c
651-0c
655-0c
661-0c
665-0c
671-0c
644-0c
643-0c
642-0c
0x0c
0x03
653-0c
652-0c
663-0c
662-0c
0→16
16
BROADCASTING RESETTING NON-ARRIVAL COUNTER
631-0e
641-0e
654-0e
651-0e
655-0e
661-0e
665-0e
671-0e
644-0e
643-0e
642-0e
0x0e
653-0e
652-0e
664-0e
673-0e
663-0e
662-0e
672-0e
631-0f
641-0f
654-0f
651-0f
655-0f
661-0f
665-0f
671-0f
644-0f
643-0f
642-0f
0x0f
653-0f
652-0f
664-0f
673-0f
663-0f
662-0f
672-0f

F I G. 1 1 D


SYNCHRONIZATION COMPLETION (TOP PART)
MIDDLE PART SYNCHRONIZATION COMPLETION TO TOP PART SYNCHRONIZATION
SHARED UNIT INVERTING BARRIER STATE
NON-ARRIVAL COUNTER
EXPECTATION COUNTER
ID
MASK
0→1
1→0
0x00
0x01
0x02
0x03
0x0c
16
1

F I G. 1 2 A

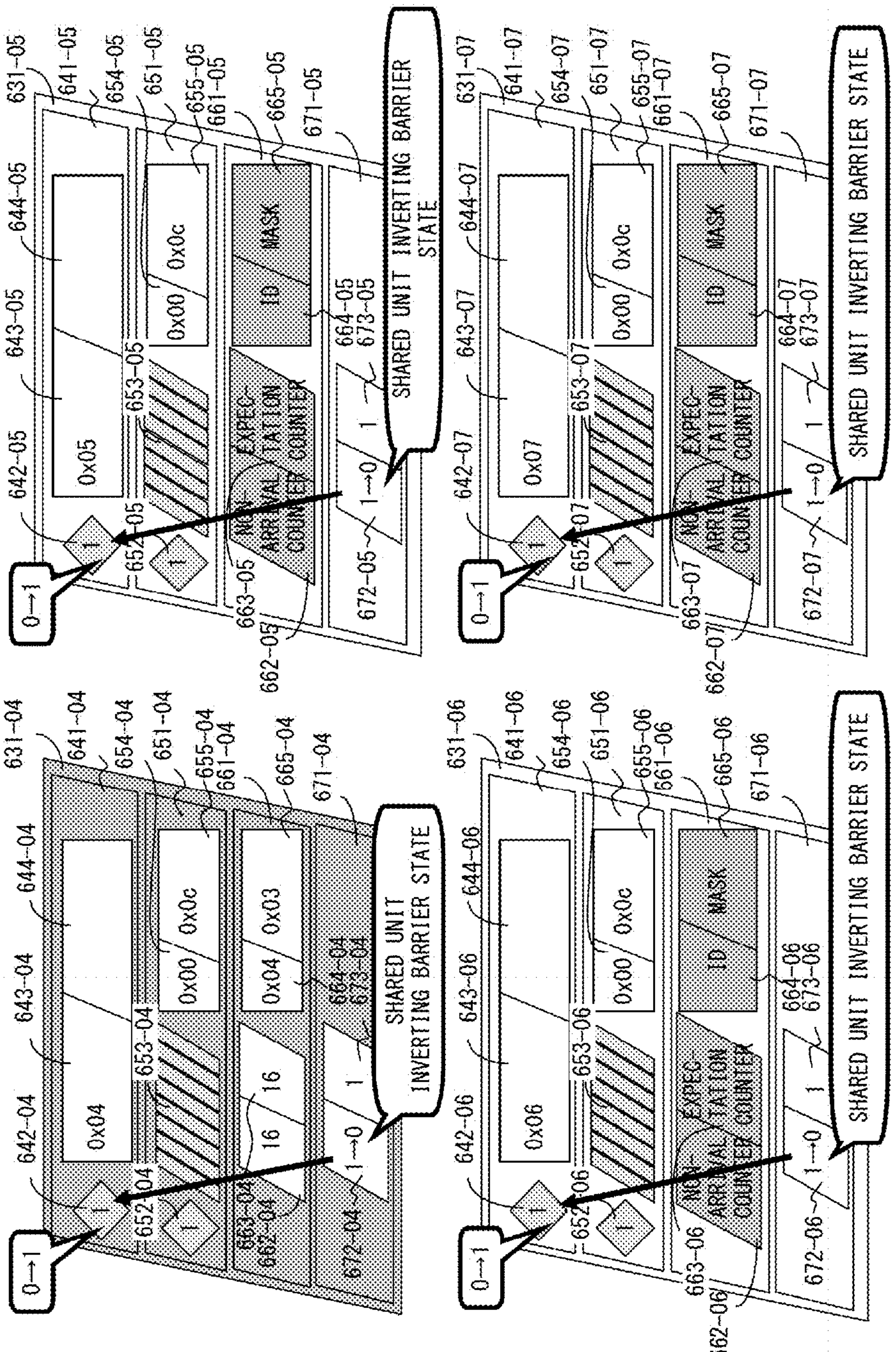

631-04
641-04
654-04
651-04
655-04
661-04
665-04
671-04
644-04
643-04
642-04
653-04
652-04
663-04
662-04
664-04
673-04
672-04
0x04
0x00
0x0c
0x04
0x03
16
16
1
1→0
0→1
SHARED UNIT INVERTING BARRIER STATE
631-05
641-05
654-05
651-05
655-05
661-05
665-05
671-05
644-05
643-05
642-05
653-05
652-05
663-05
662-05
664-05
673-05
672-05
0x05
0x00
0x0c
ID
MASK
NON-ARRIVAL COUNTER
EXPECTATION COUNTER
1
1→0
0→1
SHARED UNIT INVERTING BARRIER STATE
631-06
641-06
654-06
651-06
655-06
661-06
665-06
671-06
644-06
643-06
642-06
653-06
652-06
663-06
662-06
664-06
673-06
672-06
0x06
0x00
0x0c
ID
MASK
NON-ARRIVAL COUNTER
EXPECTATION COUNTER
1
1→0
0→1
SHARED UNIT INVERTING BARRIER STATE
631-07
641-07
654-07
651-07
655-07
661-07
665-07
671-07
644-07
643-07
642-07
653-07
652-07
663-07
662-07
664-07
673-07
672-07
0x07
0x00
0x0c
ID
MASK
NON-ARRIVAL COUNTER
EXPECTATION COUNTER
1
1→0
0→1
SHARED UNIT INVERTING BARRIER STATE

FIG. 12B

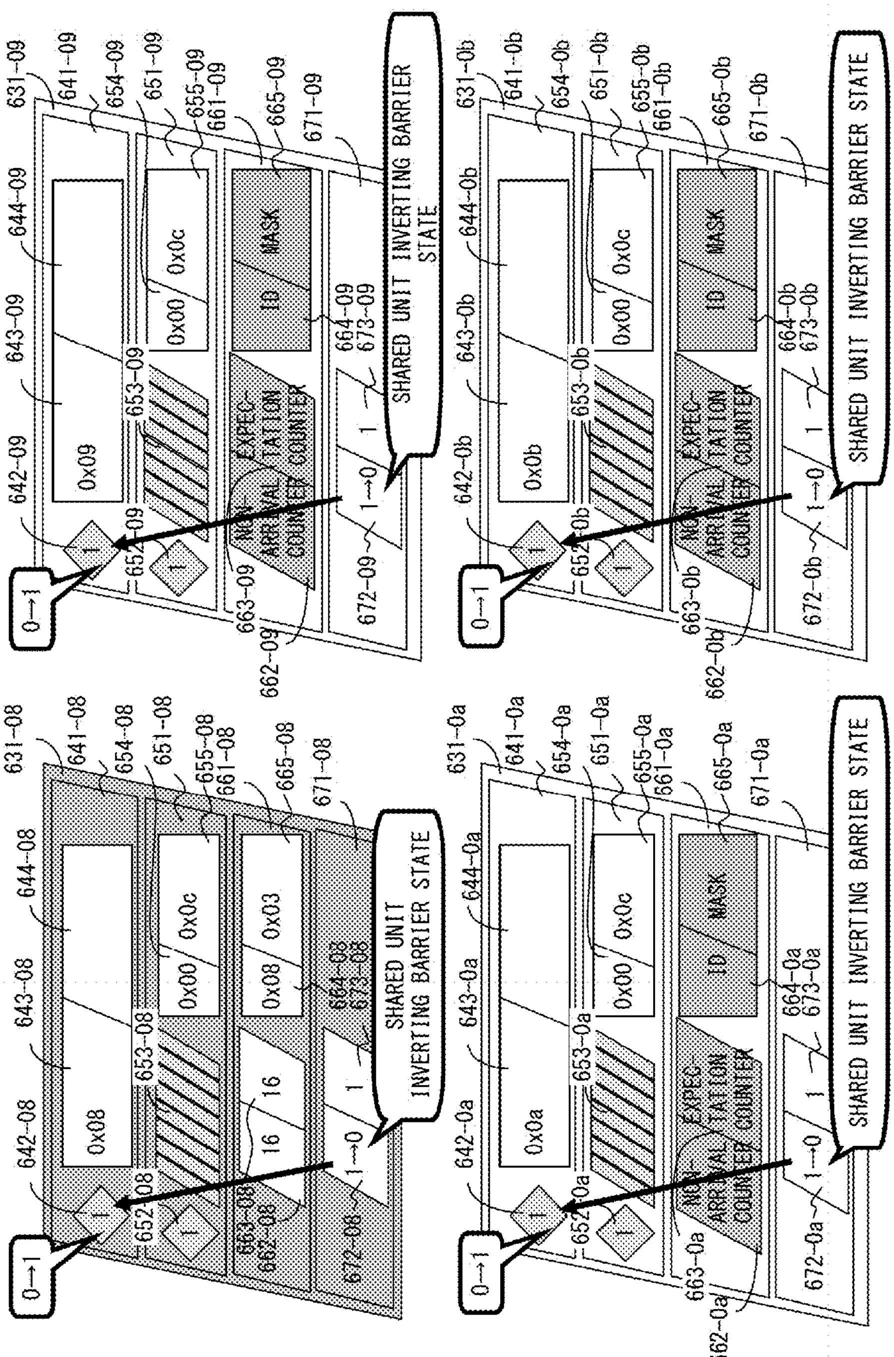
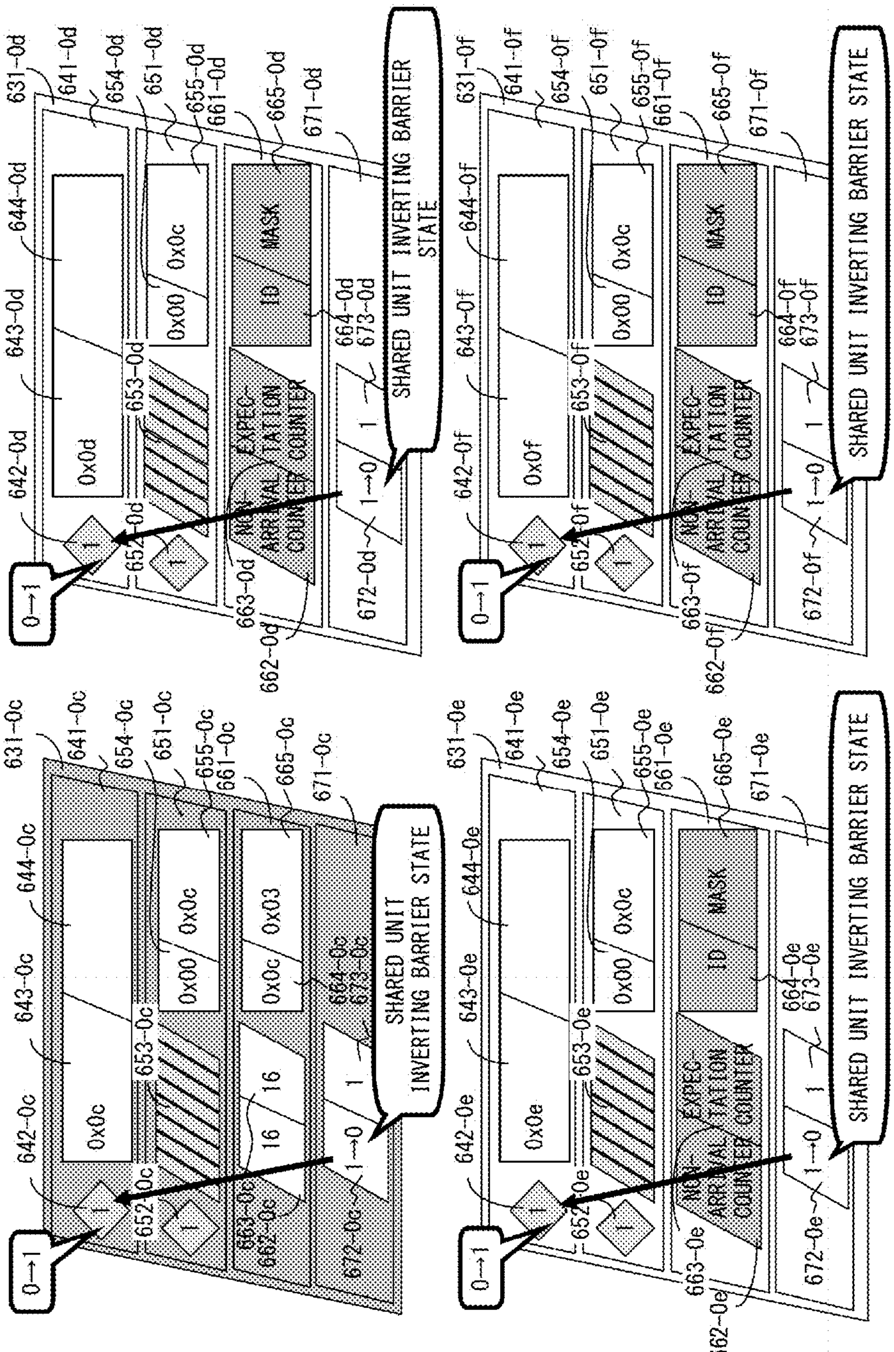

SHARED UNIT INVERTING BARRIER STATE
SHARED UNIT INVERTING BARRIER STATE
SHARED UNIT INVERTING BARRIER STATE
SHARED UNIT INVERTING BARRIER STATE
NON-ARRIVAL COUNTER
EXPECTATION COUNTER
ID
MASK
0x08
0x09
0x0a
0x0b
0x00
0x0c
0x03
16
0→1
1→0

FIG. 12C



SHARED UNIT INVERTING BARRIER STATE
SHARED UNIT INVERTING BARRIER STATE
SHARED UNIT INVERTING BARRIER STATE
SHARED UNIT INVERTING BARRIER STATE
0→1
1→0
0x0c
0x0d
0x0e
0x0f
0x00
0x03
16
ID
MASK
NON-ARRIVAL COUNTER
EXPECTATION COUNTER
631-0c
641-0c
642-0c
643-0c
644-0c
651-0c
652-0c
653-0c
654-0c
655-0c
661-0c
662-0c
663-0c
664-0c
665-0c
671-0c
672-0c
673-0c
631-0d
641-0d
642-0d
643-0d
644-0d
651-0d
652-0d
653-0d
654-0d
655-0d
661-0d
662-0d
663-0d
664-0d
665-0d
671-0d
672-0d
673-0d
631-0e
641-0e
642-0e
643-0e
644-0e
651-0e
652-0e
653-0e
654-0e
655-0e
661-0e
662-0e
663-0e
664-0e
665-0e
671-0e
672-0e
673-0e
631-0f
641-0f
642-0f
643-0f
644-0f
651-0f
652-0f
653-0f
654-0f
655-0f
661-0f
662-0f
663-0f
664-0f
665-0f
671-0f
672-0f
673-0f

FIG. 12D

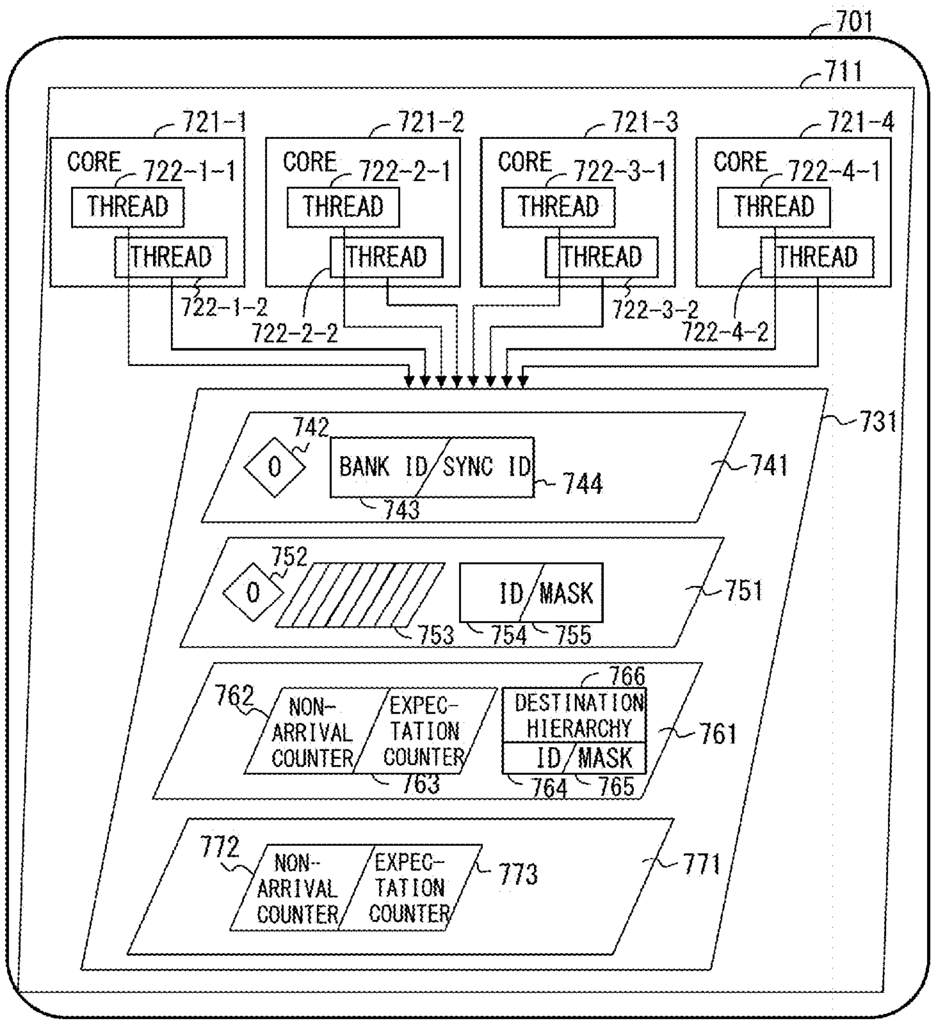
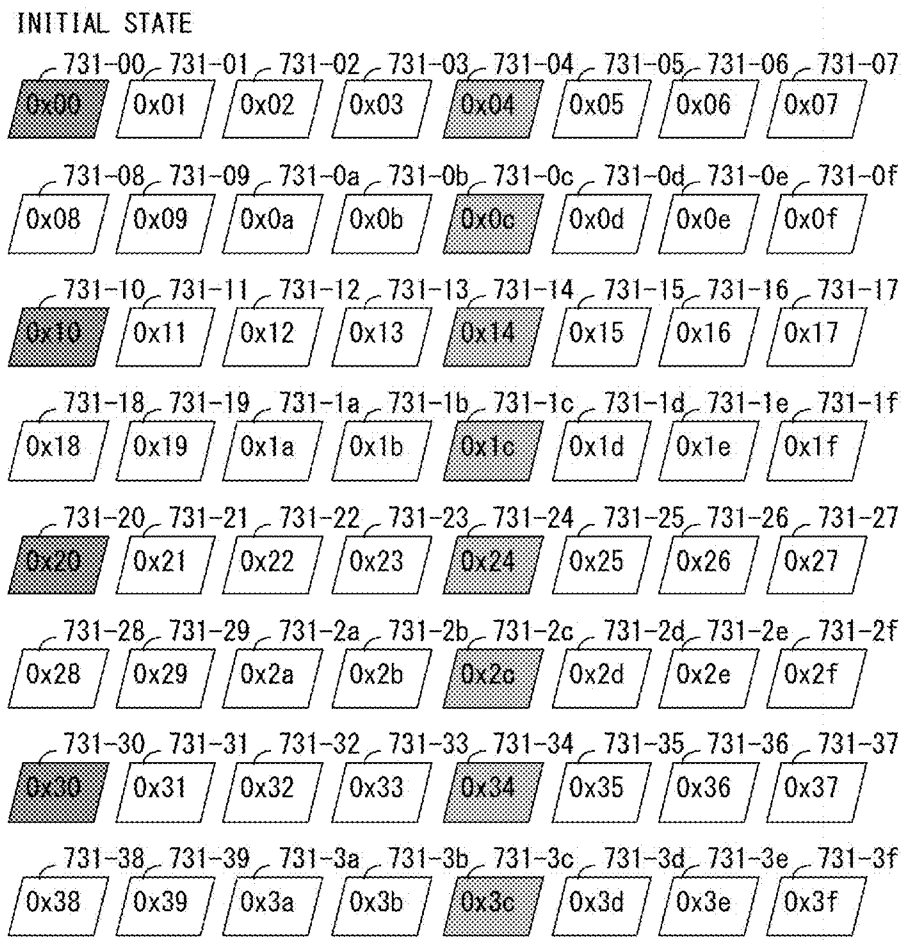

701
711
721-1
721-2
721-3
721-4
CORE
CORE
CORE
CORE
722-1-1
722-2-1
722-3-1
722-4-1
THREAD
THREAD
THREAD
THREAD
THREAD
THREAD
THREAD
THREAD
722-1-2
722-2-2
722-3-2
722-4-2
731
742
0
BANK ID/SYNC ID
744
741
743
752
0
ID/MASK
751
753
754
755
766
762
NON-ARRIVAL COUNTER
EXPECTATION COUNTER
DESTINATION HIERARCHY
ID/MASK
761
763
764
765
772
NON-ARRIVAL COUNTER
EXPECTATION COUNTER
773
771

FIG. 13


INITIAL STATE
731-00 731-01 731-02 731-03 731-04 731-05 731-06 731-07
0x00 0x01 0x02 0x03 0x04 0x05 0x06 0x07
731-08 731-09 731-0a 731-0b 731-0c 731-0d 731-0e 731-0f
0x08 0x09 0x0a 0x0b 0x0c 0x0d 0x0e 0x0f
731-10 731-11 731-12 731-13 731-14 731-15 731-16 731-17
0x10 0x11 0x12 0x13 0x14 0x15 0x16 0x17
731-18 731-19 731-1a 731-1b 731-1c 731-1d 731-1e 731-1f
0x18 0x19 0x1a 0x1b 0x1c 0x1d 0x1e 0x1f
731-20 731-21 731-22 731-23 731-24 731-25 731-26 731-27
0x20 0x21 0x22 0x23 0x24 0x25 0x26 0x27
731-28 731-29 731-2a 731-2b 731-2c 731-2d 731-2e 731-2f
0x28 0x29 0x2a 0x2b 0x2c 0x2d 0x2e 0x2f
731-30 731-31 731-32 731-33 731-34 731-35 731-36 731-37
0x30 0x31 0x32 0x33 0x34 0x35 0x36 0x37
731-38 731-39 731-3a 731-3b 731-3c 731-3d 731-3e 731-3f
0x38 0x39 0x3a 0x3b 0x3c 0x3d 0x3e 0x3f

F I G. 14

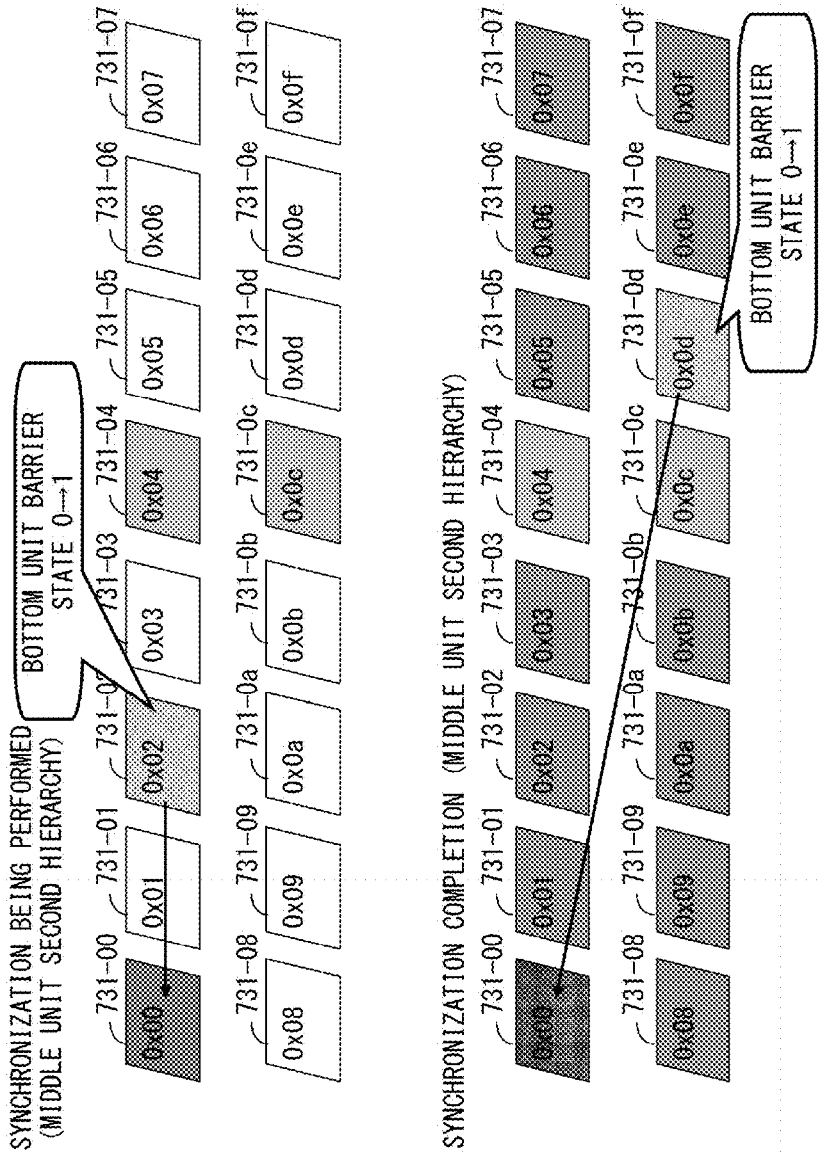
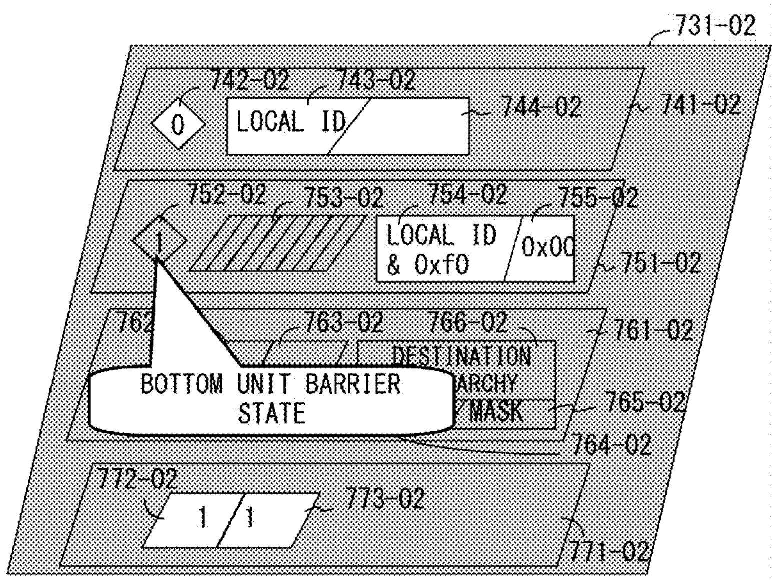

SYNCHRONIZATION BEING PERFORMED
(MIDDLE UNIT SECOND HIERARCHY)
BOTTOM UNIT BARRIER
STATE 0→1
SYNCHRONIZATION COMPLETION (MIDDLE UNIT SECOND HIERARCHY)
BOTTOM UNIT BARRIER
STATE 0→1
731-00 731-01 731-02 731-03 731-04 731-05 731-06 731-07
0x00 0x01 0x02 0x03 0x04 0x05 0x06 0x07
731-08 731-09 731-0a 731-0b 731-0c 731-0d 731-0e 731-0f
0x08 0x09 0x0a 0x0b 0x0c 0x0d 0x0e 0x0f

FIG. 15A


731-02
742-02
743-02
0
LOCAL ID
744-02
741-02
752-02
753-02
754-02
755-02
1
LOCAL ID & 0xf0
0x00
751-02
762
763-02
766-02
DESTINATION
ARCHY
MASK
761-02
BOTTOM UNIT BARRIER STATE
765-02
764-02
772-02
1
1
773-02
771-02

F I G. 1 5 B

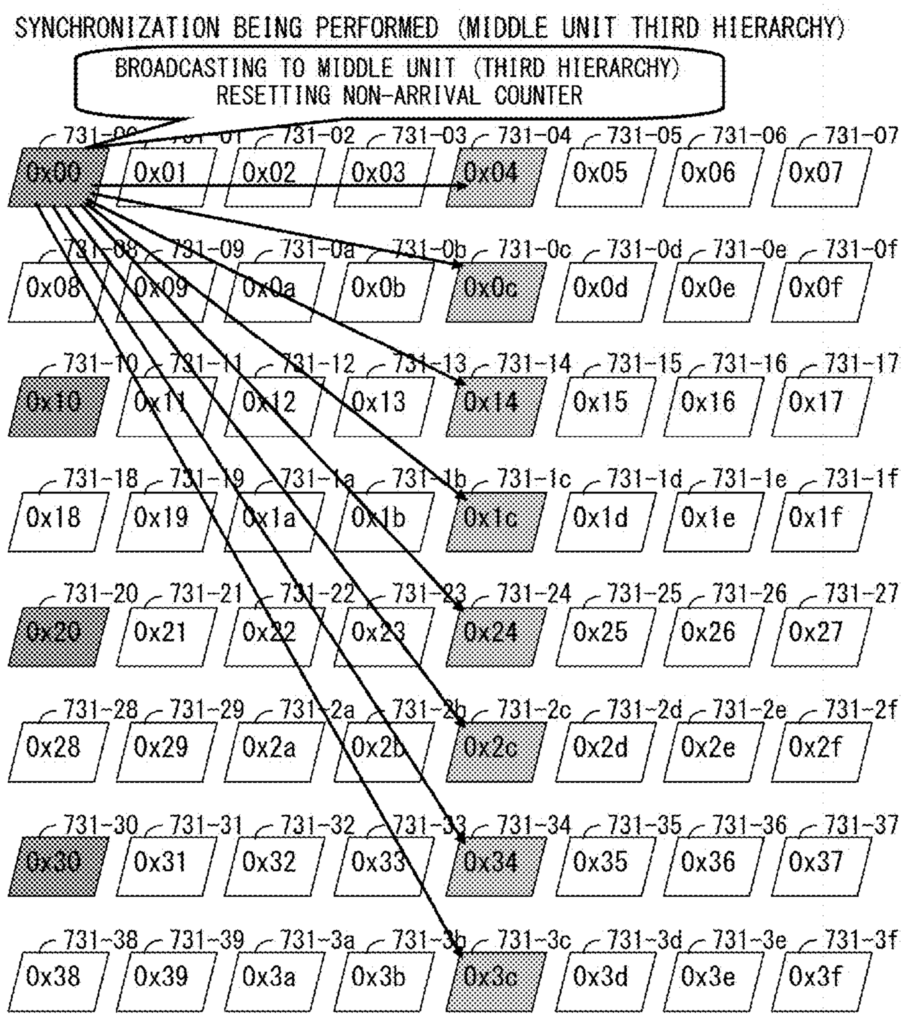

SYNCHRONIZATION BEING PERFORMED (MIDDLE UNIT THIRD HIERARCHY)
BROADCASTING TO MIDDLE UNIT (THIRD HIERARCHY)
RESETTING NON-ARRIVAL COUNTER
731-00
731-01
731-02
731-03
731-04
731-05
731-06
731-07
0x00
0x01
0x02
0x03
0x04
0x05
0x06
0x07
731-08
731-09
731-0a
731-0b
731-0c
731-0d
731-0e
731-0f
0x08
0x09
0x0a
0x0b
0x0c
0x0d
0x0e
0x0f
731-10
731-11
731-12
731-13
731-14
731-15
731-16
731-17
0x10
0x11
0x12
0x13
0x14
0x15
0x16
0x17
731-18
731-19
731-1a
731-1b
731-1c
731-1d
731-1e
731-1f
0x18
0x19
0x1a
0x1b
0x1c
0x1d
0x1e
0x1f
731-20
731-21
731-22
731-23
731-24
731-25
731-26
731-27
0x20
0x21
0x22
0x23
0x24
0x25
0x26
0x27
731-28
731-29
731-2a
731-2b
731-2c
731-2d
731-2e
731-2f
0x28
0x29
0x2a
0x2b
0x2c
0x2d
0x2e
0x2f
731-30
731-31
731-32
731-33
731-34
731-35
731-36
731-37
0x30
0x31
0x32
0x33
0x34
0x35
0x36
0x37
731-38
731-39
731-3a
731-3b
731-3c
731-3d
731-3e
731-3f
0x38
0x39
0x3a
0x3b
0x3c
0x3d
0x3e
0x3f

FIG. 16A

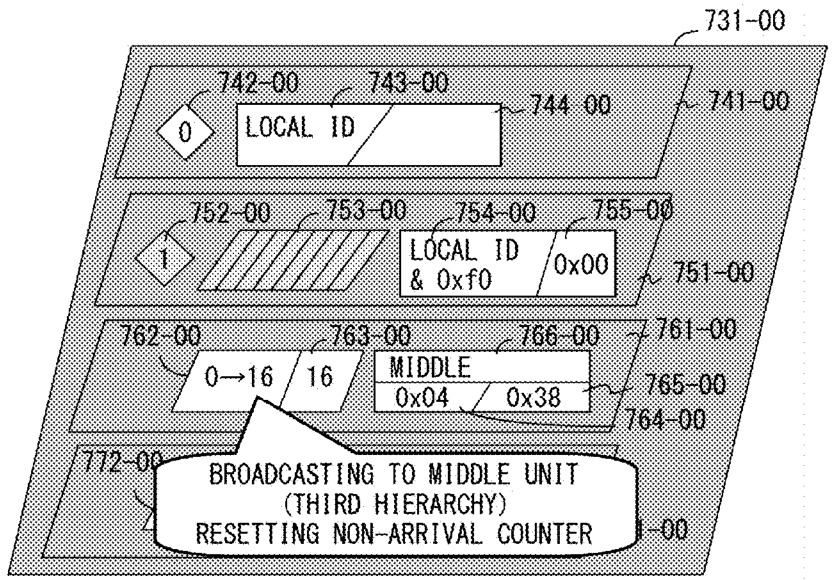
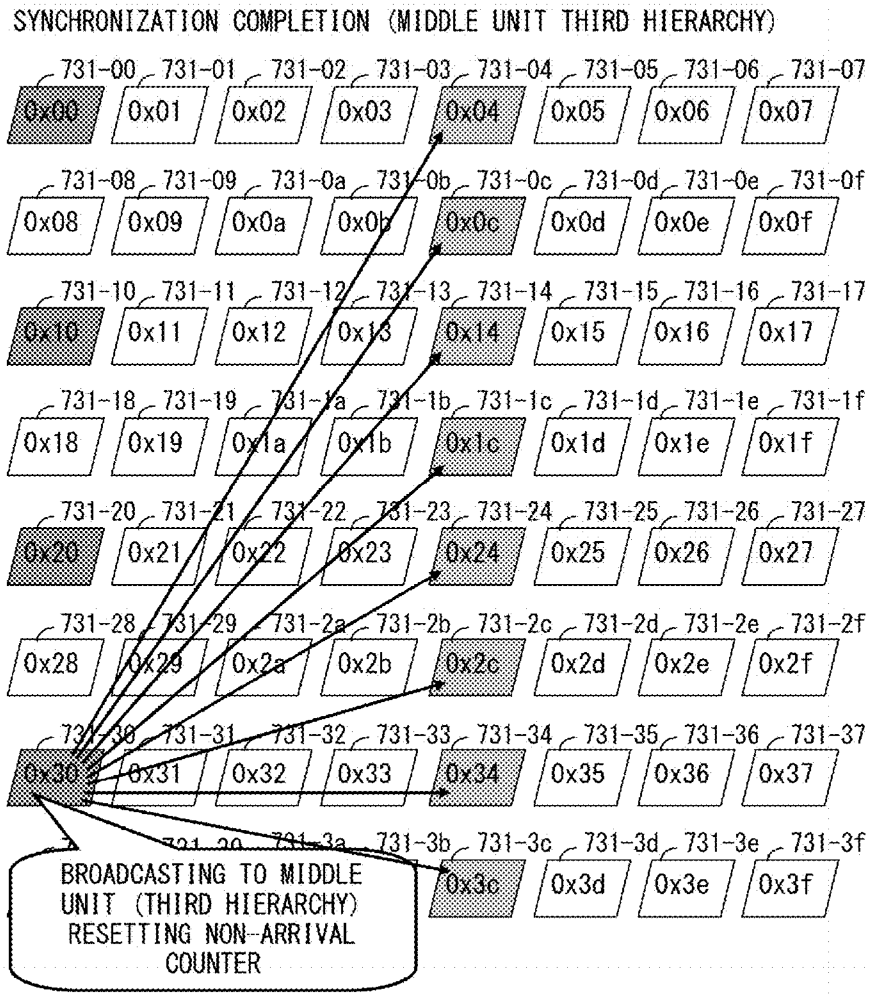
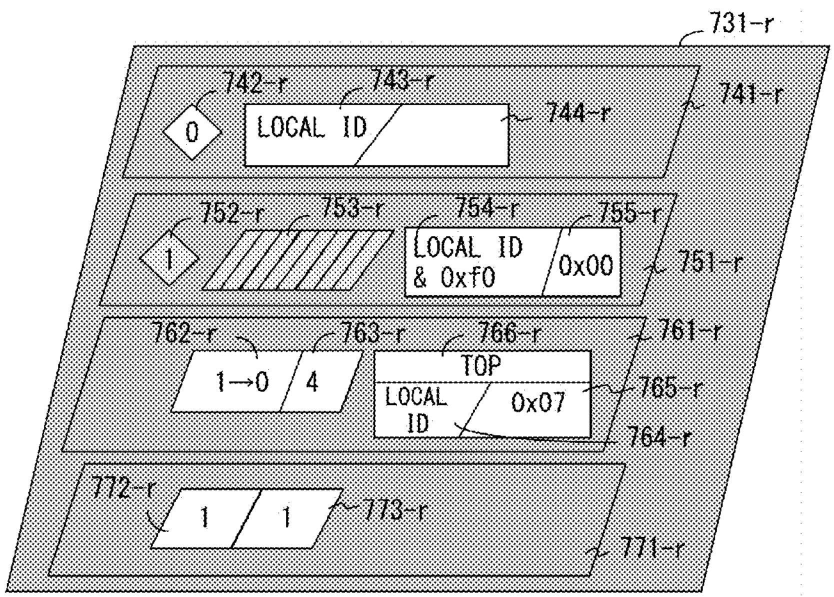

731-00
741-00
742-00
743-00
744 00
0
LOCAL ID
752-00
753-00
754-00
755-00
1
LOCAL ID & 0xf0
0x00
751-00
761-00
762-00
763-00
766-00
0→16
16
MIDDLE
0x04
0x38
765-00
764-00
772-00
BROADCASTING TO MIDDLE UNIT (THIRD HIERARCHY) RESETTING NON-ARRIVAL COUNTER

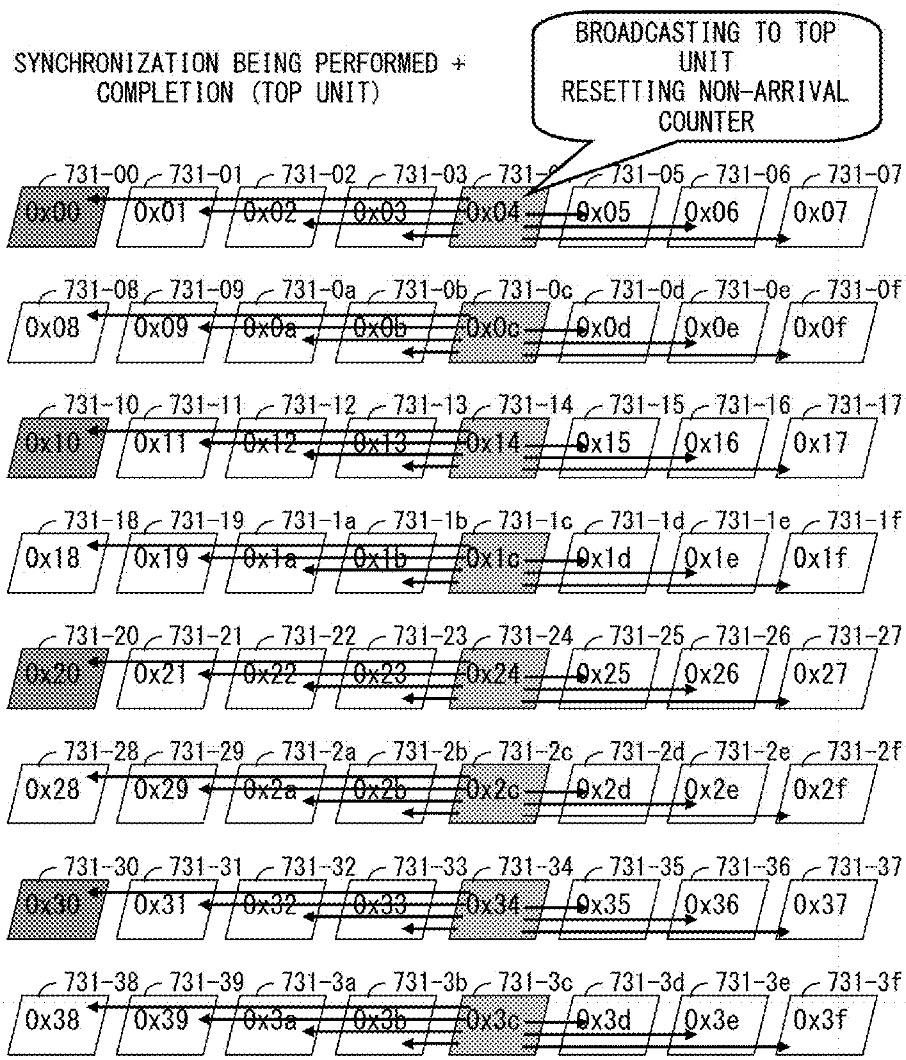
FIG. 16B


SYNCHRONIZATION COMPLETION (MIDDLE UNIT THIRD HIERARCHY)
731-00
731-01
731-02
731-03
731-04
731-05
731-06
731-07
0x00
0x01
0x02
0x03
0x04
0x05
0x06
0x07
731-08
731-09
731-0a
731-0b
731-0c
731-0d
731-0e
731-0f
0x08
0x09
0x0a
0x0b
0x0c
0x0d
0x0e
0x0f
731-10
731-11
731-12
731-13
731-14
731-15
731-16
731-17
0x10
0x11
0x12
0x13
0x14
0x15
0x16
0x17
731-18
731-19
731-1a
731-1b
731-1c
731-1d
731-1e
731-1f
0x18
0x19
0x1a
0x1b
0x1c
0x1d
0x1e
0x1f
731-20
731-21
731-22
731-23
731-24
731-25
731-26
731-27
0x20
0x21
0x22
0x23
0x24
0x25
0x26
0x27
731-28
731-29
731-2a
731-2b
731-2c
731-2d
731-2e
731-2f
0x28
0x29
0x2a
0x2b
0x2c
0x2d
0x2e
0x2f
731-30
731-31
731-32
731-33
731-34
731-35
731-36
731-37
0x30
0x31
0x32
0x33
0x34
0x35
0x36
0x37
731-3b
731-3c
731-3d
731-3e
731-3f
0x3c
0x3d
0x3e
0x3f
BROADCASTING TO MIDDLE UNIT (THIRD HIERARCHY) RESETTING NON-ARRIVAL COUNTER

F I G. 1 7 A

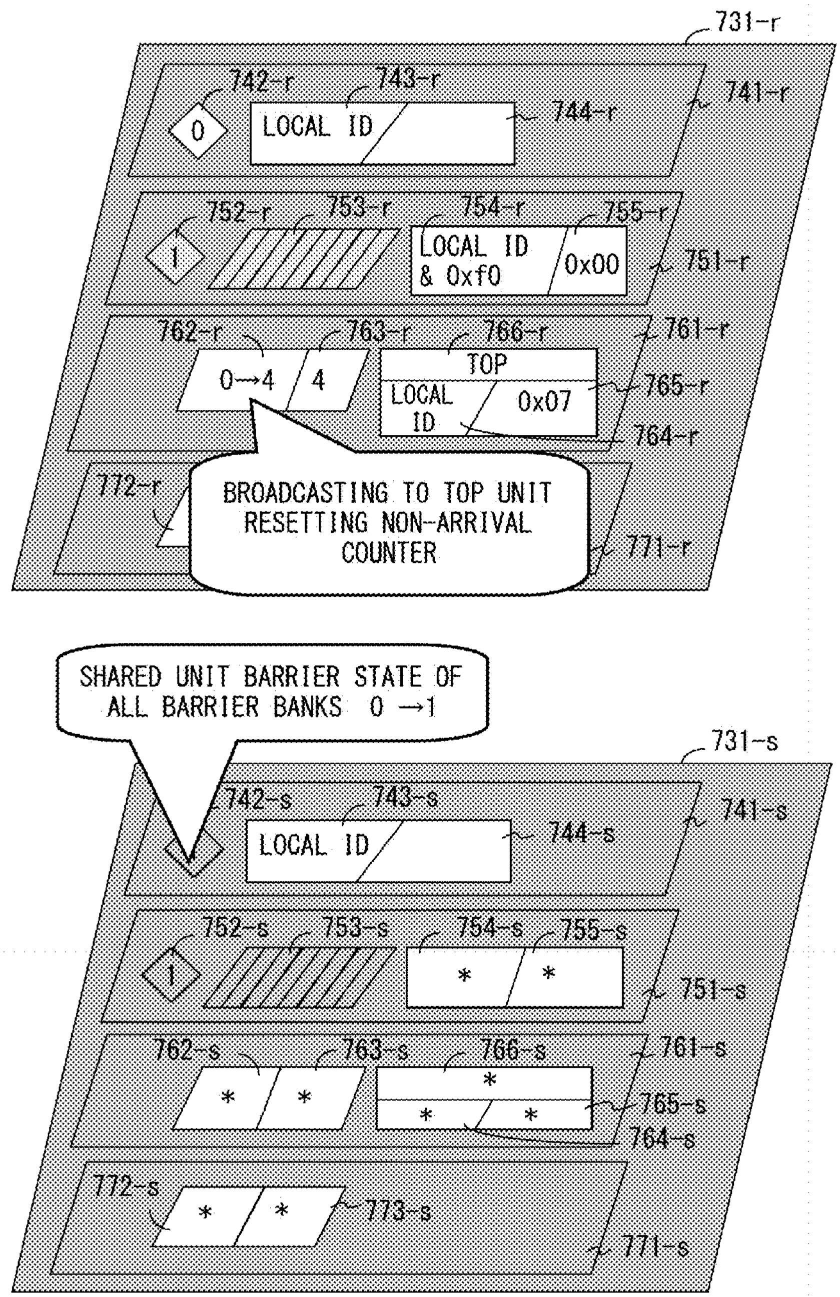

731-r
742-r
743-r
741-r
0
LOCAL ID
744-r
752-r
753-r
754-r
755-r
1
LOCAL ID
& 0xf0
0x00
751-r
762-r
763-r
766-r
761-r
1→0
4
TOP
LOCAL
ID
0x07
765-r
764-r
772-r
1
1
773-r
771-r

F I G. 17B



SYNCHRONIZATION BEING PERFORMED + COMPLETION (TOP UNIT)
BROADCASTING TO TOP UNIT
RESETTING NON-ARRIVAL COUNTER
731-00 0x00
731-01 0x01
731-02 0x02
731-03 0x03
0x04
731-05 0x05
731-06 0x06
731-07 0x07
731-08 0x08
731-09 0x09
731-0a 0x0a
731-0b 0x0b
731-0c 0x0c
731-0d 0x0d
731-0e 0x0e
731-0f 0x0f
731-10 0x10
731-11 0x11
731-12 0x12
731-13 0x13
731-14 0x14
731-15 0x15
731-16 0x16
731-17 0x17
731-18 0x18
731-19 0x19
731-1a 0x1a
731-1b 0x1b
731-1c 0x1c
731-1d 0x1d
731-1e 0x1e
731-1f 0x1f
731-20 0x20
731-21 0x21
731-22 0x22
731-23 0x23
731-24 0x24
731-25 0x25
731-26 0x26
731-27 0x27
731-28 0x28
731-29 0x29
731-2a 0x2a
731-2b 0x2b
731-2c 0x2c
731-2d 0x2d
731-2e 0x2e
731-2f 0x2f
731-30 0x30
731-31 0x31
731-32 0x32
731-33 0x33
731-34 0x34
731-35 0x35
731-36 0x36
731-37 0x37
731-38 0x38
731-39 0x39
731-3a 0x3a
731-3b 0x3b
731-3c 0x3c
731-3d 0x3d
731-3e 0x3e
731-3f 0x3f

FIG. 18A


731-r
742-r
743-r
741-r
0
LOCAL ID
744-r
752-r
753-r
754-r
755-r
1
LOCAL ID & 0xf0
0x00
751-r
762-r
763-r
766-r
761-r
0→4
4
TOP
LOCAL ID
0x07
765-r
764-r
772-r
BROADCASTING TO TOP UNIT RESETTING NON-ARRIVAL COUNTER
771-r
SHARED UNIT BARRIER STATE OF ALL BARRIER BANKS 0 →1
731-s
742-s
743-s
741-s
LOCAL ID
744-s
752-s
753-s
754-s
755-s
1
*
*
751-s
762-s
763-s
766-s
761-s
*
*
*
765-s
*
*
764-s
772-s
*
*
773-s
771-s

F I G. 1 8 B

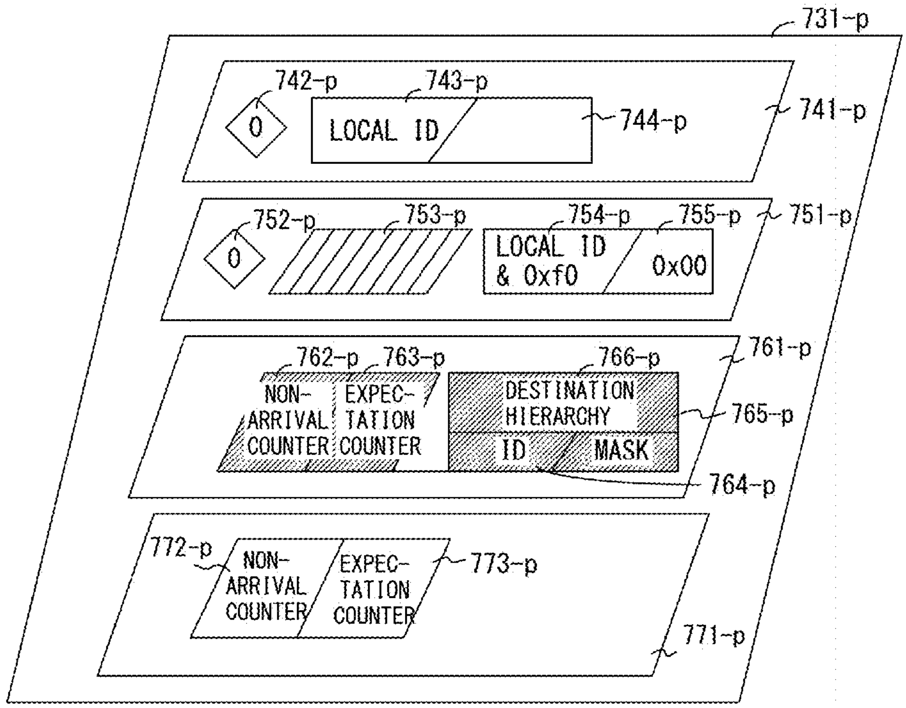
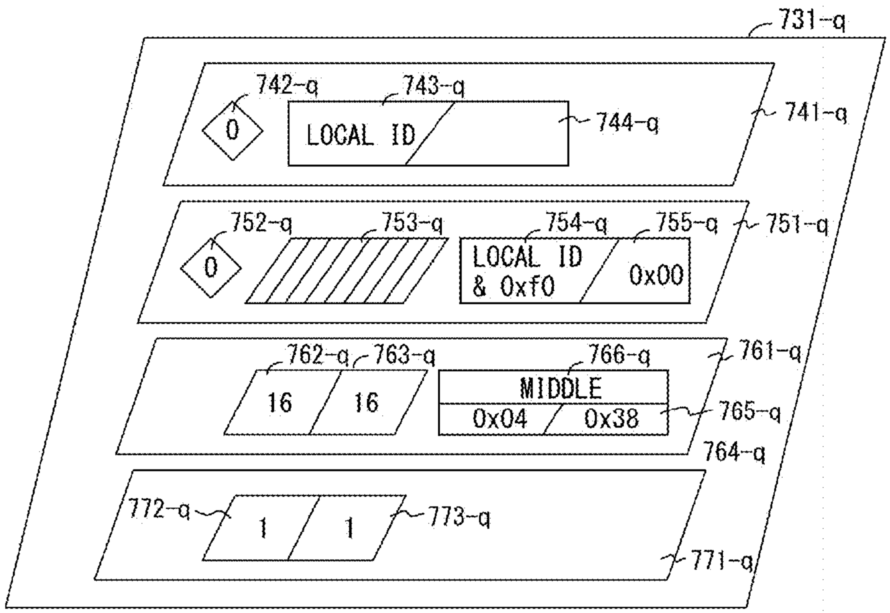
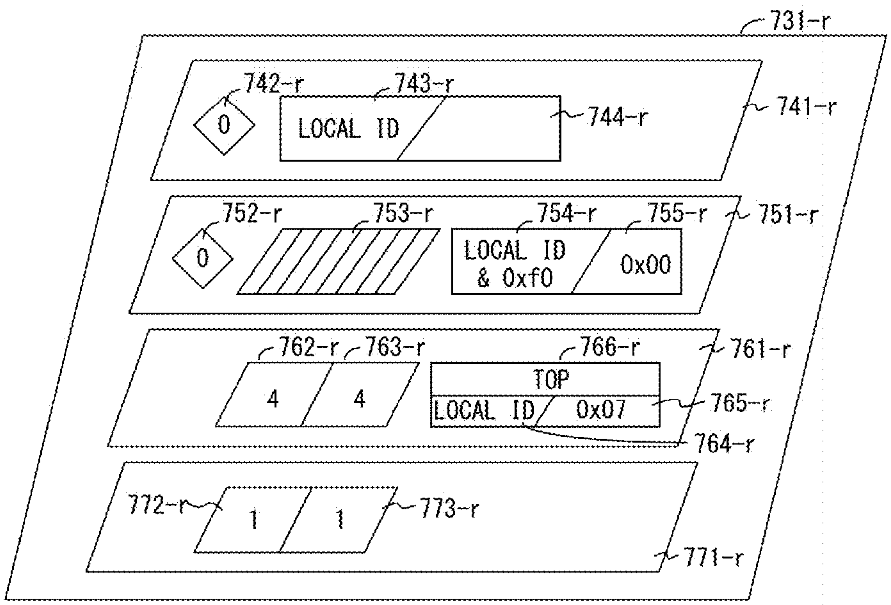

731-p
741-p
742-p
743-p
0
LOCAL ID
744-p
751-p
752-p
753-p
754-p
755-p
0
LOCAL ID & 0xf0
0x00
761-p
762-p
763-p
766-p
NON-ARRIVAL COUNTER
EXPEC-TATION COUNTER
DESTINATION HIERARCHY
ID
MASK
765-p
764-p
772-p
NON-ARRIVAL COUNTER
EXPEC-TATION COUNTER
773-p
771-p

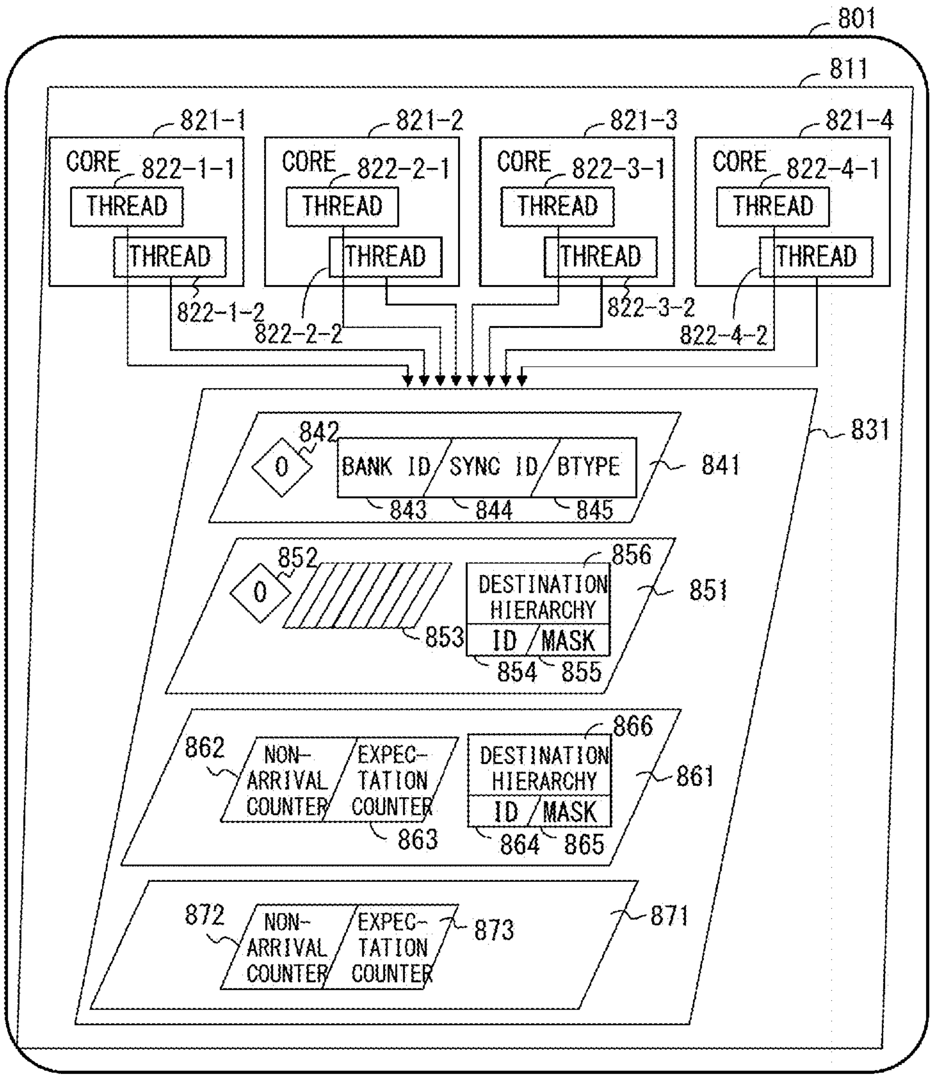
FIG. 19A


731-q
742-q
743-q
0
LOCAL ID
744-q
741-q
752-q
753-q
754-q
755-q
751-q
0
LOCAL ID
& 0xf0
0x00
762-q
763-q
766-q
761-q
16
16
MIDDLE
0x04
0x38
765-q
764-q
772-q
1
1
773-q
771-q

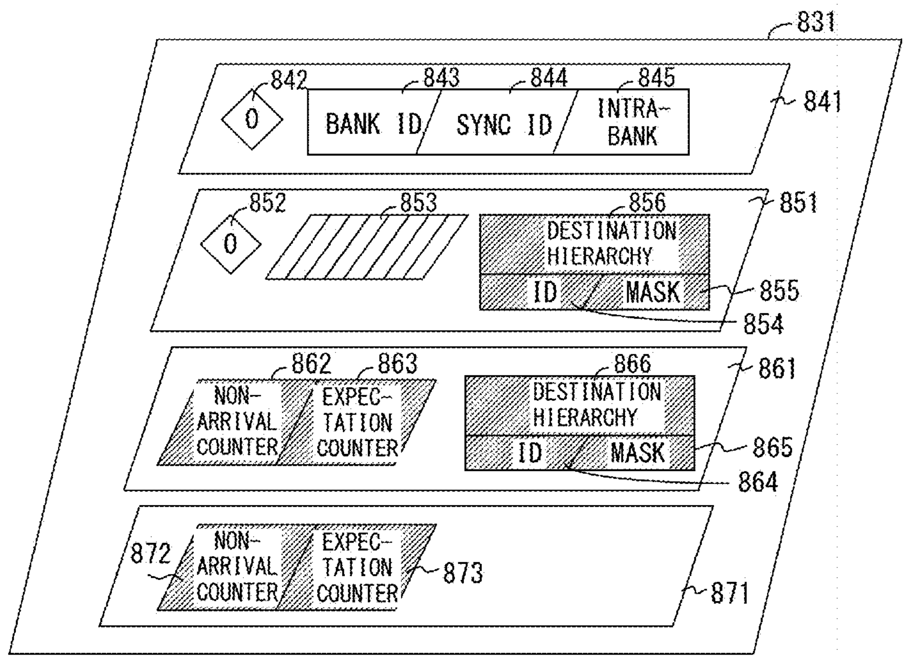
F I G. 1 9 B


731-r
741-r
742-r
743-r
744-r
0
LOCAL ID
751-r
752-r
753-r
754-r
755-r
0
LOCAL ID
& 0xf0
0x00
761-r
762-r
763-r
766-r
4
4
TOP
LOCAL ID
0x07
765-r
764-r
771-r
772-r
773-r
1
1

F I G. 1 9 C


801
811
821-1
821-2
821-3
821-4
CORE
822-1-1
822-2-1
822-3-1
822-4-1
THREAD
THREAD
822-1-2
822-2-2
822-3-2
822-4-2
831
842
0
BANK ID
SYNC ID
BTYPE
841
843
844
845
852
856
DESTINATION HIERARCHY
ID
MASK
851
853
854
855
862
NON-ARRIVAL COUNTER
EXPEC-TATION COUNTER
866
861
863
864
865
872
873
871

F I G. 2 0


831
841
842
0
843
BANK ID
844
SYNC ID
845
INTRA-
BANK
851
852
0
853
856
DESTINATION
HIERARCHY
ID
MASK
855
854
861
862
NON-
ARRIVAL
COUNTER
863
EXPEC-
TATION
COUNTER
866
DESTINATION
HIERARCHY
ID
MASK
865
864
871
872
NON-
ARRIVAL
COUNTER
EXPEC-
TATION
COUNTER
873

F I G. 2 1 A

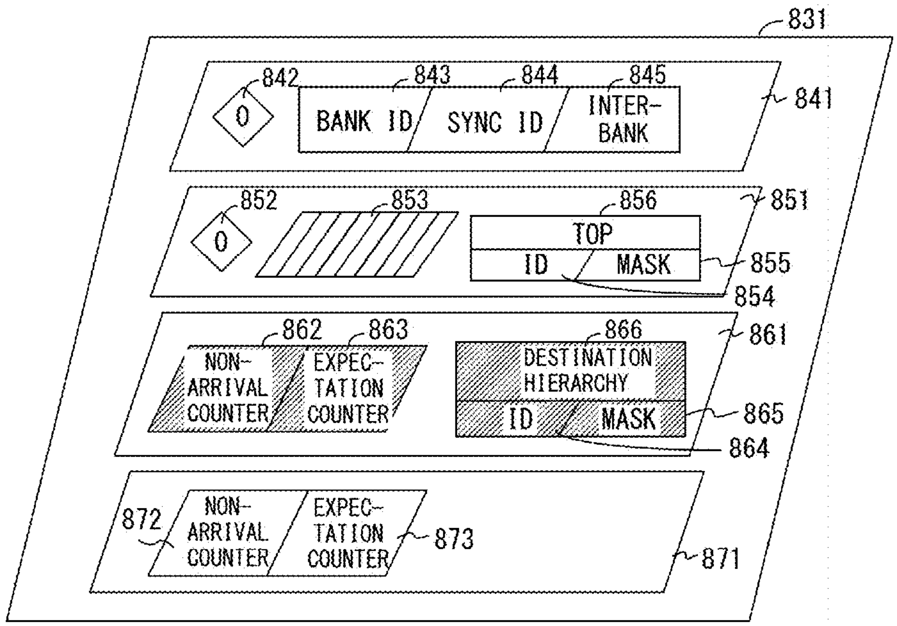
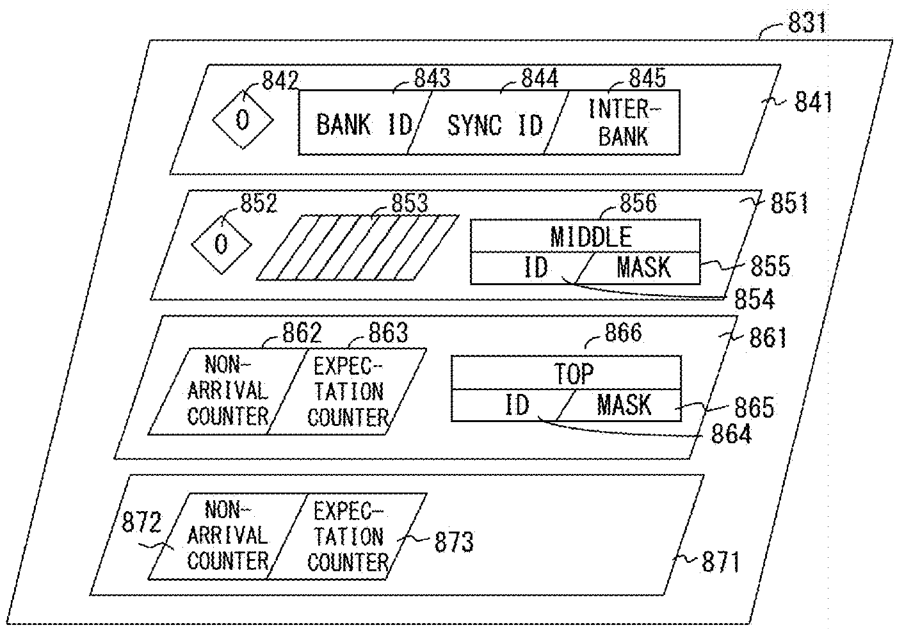
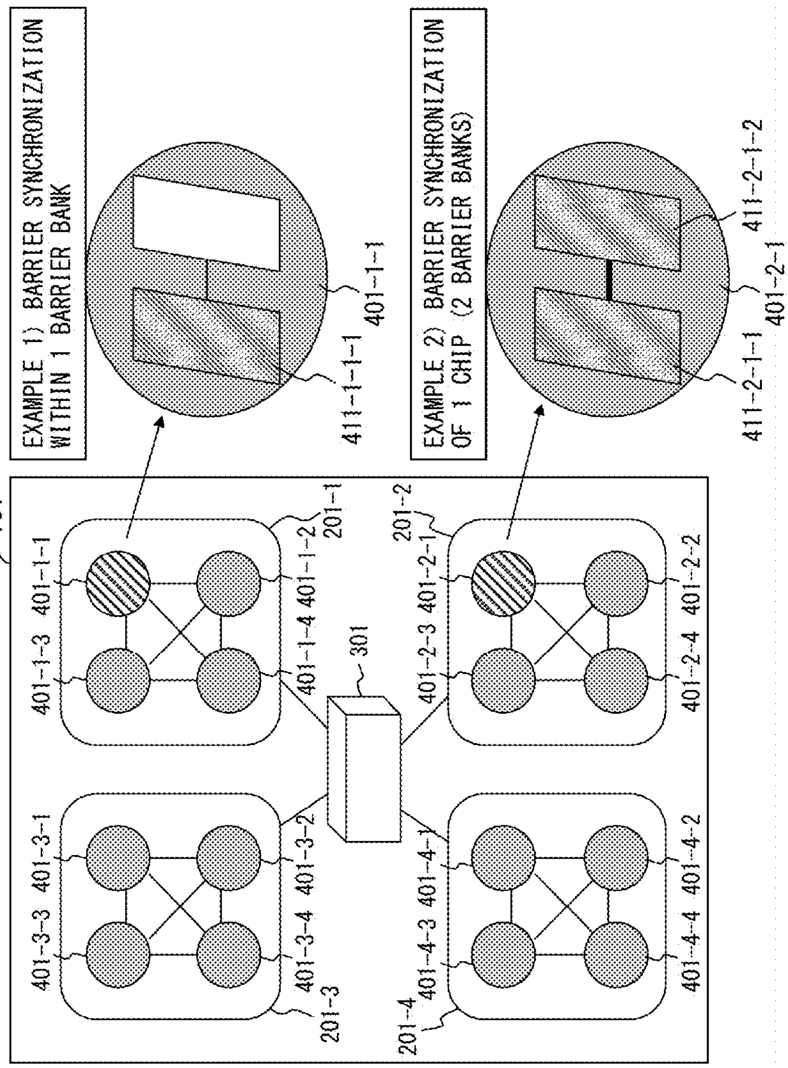

831
841
0
842
843
BANK ID
844
SYNC ID
845
INTER-BANK
851
0
852
853
856
TOP
ID
MASK
855
854
861
862
NON-ARRIVAL COUNTER
863
EXPECTATION COUNTER
866
DESTINATION HIERARCHY
ID
MASK
865
864
872
NON-ARRIVAL COUNTER
EXPECTATION COUNTER
873
871

FIG. 21B


831
842
0
843
BANK ID
844
SYNC ID
845
INTER-
BANK
841
852
0
853
856
MIDDLE
ID
MASK
851
855
854
862
NON-
ARRIVAL
COUNTER
863
EXPEC-
TATION
COUNTER
866
TOP
ID
MASK
861
865
864
872
NON-
ARRIVAL
COUNTER
EXPEC-
TATION
COUNTER
873
871

F I G. 2 1 C



EXAMPLE 1) BARRIER SYNCHRONIZATION WITHIN 1 BARRIER BANK
EXAMPLE 2) BARRIER SYNCHRONIZATION OF 1 CHIP (2 BARRIER BANKS)
411-1-1-1
401-1-1
411-2-1-1
411-2-1-2
401-2-1
101
301
201-1
201-2
201-3
201-4
401-1-1
401-1-2
401-1-3
401-1-4
401-2-1
401-2-2
401-2-3
401-2-4
401-3-1
401-3-2
401-3-3
401-3-4
401-4-1
401-4-2
401-4-3
401-4-4

FIG. 22A

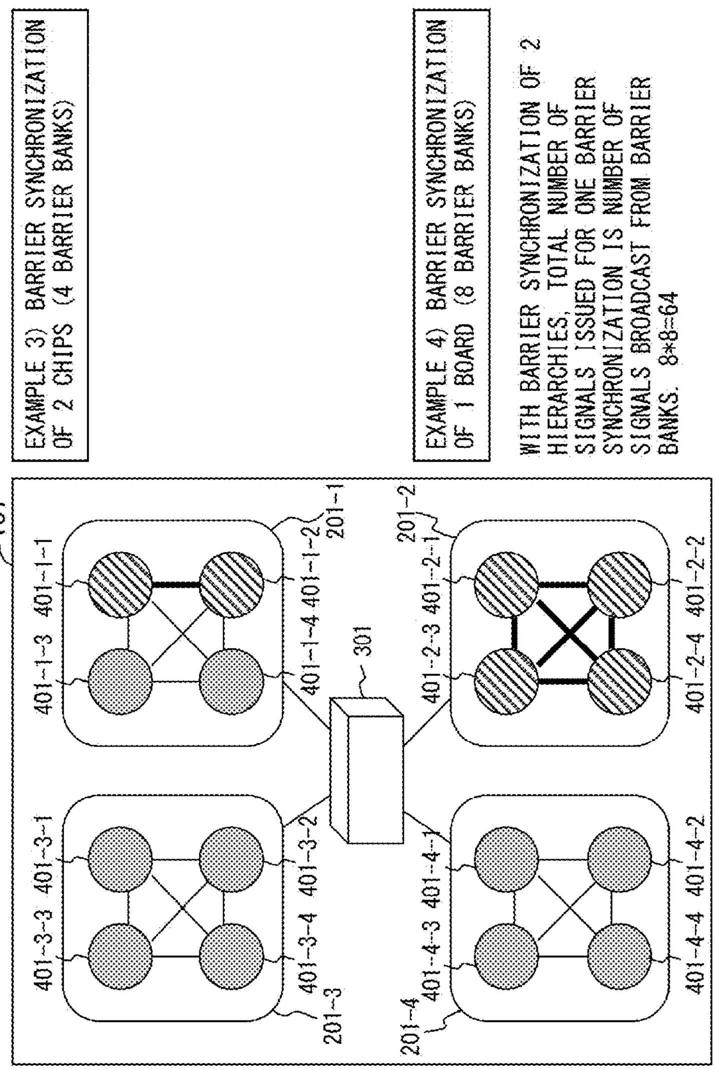
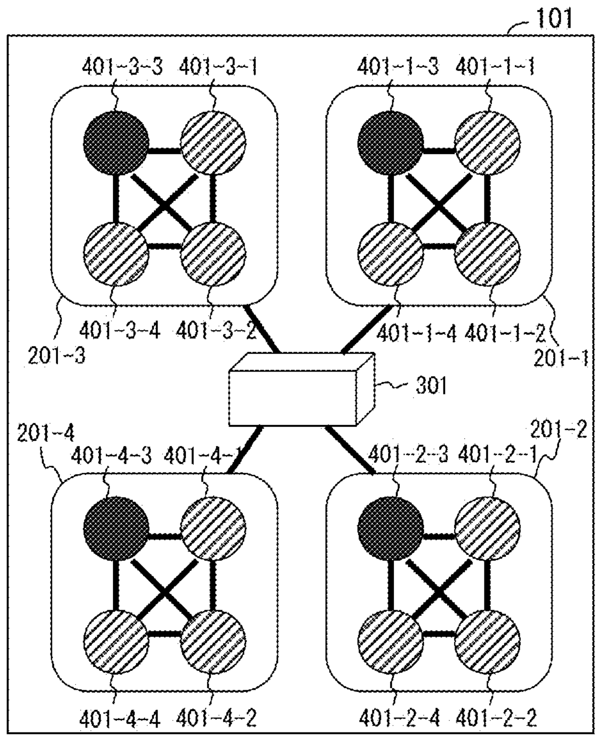

EXAMPLE 3) BARRIER SYNCHRONIZATION OF 2 CHIPS (4 BARRIER BANKS)
EXAMPLE 4) BARRIER SYNCHRONIZATION OF 1 BOARD (8 BARRIER BANKS)
WITH BARRIER SYNCHRONIZATION OF 2 HIERARCHIES, TOTAL NUMBER OF SIGNALS ISSUED FOR ONE BARRIER SYNCHRONIZATION IS NUMBER OF SIGNALS BROADCAST FROM BARRIER BANKS. 8*8=64
101
301
201-1
201-2
201-3
201-4
401-1-1
401-1-2
401-1-3
401-1-4
401-2-1
401-2-2
401-2-3
401-2-4
401-3-1
401-3-2
401-3-3
401-3-4
401-4-1
401-4-2
401-4-3
401-4-4

FIG. 22B



EXAMPLE 5) BARRIER SYNCHRONIZATION OF ENTIRE SERVER (32 BARRIER BANKS)

WITH BARRIER SYNCHRONIZATION OF 2 HIERARCHIES, TOTAL NUMBER OF SIGNALS ISSUED FOR ONE BARRIER SYNCHRONIZATION IS NUMBER OF SIGNALS BROADCAST FROM BARRIER BANKS. 32*32=1024 (32*24=768 VIA SWITCH)

WITH BARRIER SYNCHRONIZATION OF 3 HIERARCHIES, TOTAL NUMBER OF SIGNALS ISSUED FOR ONE BARRIER SYNCHRONIZATION IS NUMBER OF SIGNALS BROADCAST TO LIMITED RANGE IN SECOND HIERARCHY + NUMBER OF SIGNALS BROADCAST TO LIMITED RANGE IN THIRD HIERARCHY. 32*4+4*8=160 (32*3=96 VIA SWITCH)

F I G. 2 2 C

INFORMATION PROCESSING DEVICE AND BARRIER SYNCHRONIZATION METHOD

CROSS-REFERENCE TO RELATED APPLICATION

This application is based upon and claims the benefit of priority of the prior Japanese Patent Application No. 2012-161392, filed on Jul. 20, 2012, the entire contents of which are incorporated herein by reference.

FIELD

The embodiments discussed herein are related to an information processing device and a barrier synchronization method.

BACKGROUND

Currently, parallel processing is executed for high performance computing.

"Parallel processing" in computers is for making one task run in a plurality of processor cores. This is a technique for improving a processing efficiency by using the fact that a task for solving a problem can in most cases be divided into smaller tasks.

To execute parallel processing for one task, "synchronization" for making processes of processor cores wait for one another is requested. A barrier in parallel processing is one synchronization method, by which execution of a thread or a process is suspended at a particular point in a source code in order to wait for other threads or processes, and the execution is resumed when all the other threads have arrived at a barrier.

FIGS. **1**A to **1**C illustrate conventional synchronization within a barrier bank.

FIG. **1**A illustrates an initial state, FIG. **1**B illustrates the synchronization being performed, and FIG. **1**C illustrates completion of the synchronization.

In the barrier bank **1001**, which is a minimum range of barrier synchronization, processor cores **1002**-*a* (a=1 to 4) and a barrier synchronization mechanism **1003** are provided. The barrier bank **1001** is provided within a central processing unit (CPU).

Each of the processor cores **1002**-*a* has a simultaneous multi-threading function, and has hardware threads **1004**-*a*-*b* (b=1, 2) for executing a thread.

In FIG. **1**, one processor core provides two hardware threads. Software (such as an operating system (OS)) that issues a software thread handles each of the hardware threads **1004**-*a*-*b* as a logical CPU (virtual CPU).

The barrier synchronization mechanism **1003** has a barrier state **1005** and a bitmap group **1006**.

The barrier state **1005** is information used to control the barrier synchronization. A value of the barrier state **1005** is "0" or "1".

The bitmap group **1006** includes a plurality of bitmaps. Each of the bitmaps is information indicating that the hardware thread **1004** has arrived at a barrier synchronization point. The same number of bitmaps are prepared as the number of hardware threads **1004** within the barrier bank **1001**, and they are respectively allocated to the hardware threads **1004**. Namely, each of the bitmaps indicates that an allocated hardware thread **1004** has arrived at a barrier synchronization point. A value of each of the bitmaps is "0" or "1".

In the initial state illustrated in FIG. **1**A, the barrier state **1005** and all the bitmaps are "0".

Assume that each of the hardware threads **1004** executes a thread and the hardware threads **1004-1-1**, **1004-3-1** and **1004-4-2** have arrived at a barrier synchronization point in FIG. **1**B.

The hardware threads **1004-1-1**, **1004-3-1** and **1004-4-2** read the barrier state **1005**, and respectively write a value obtained by inverting the read value to the respectively allocated bitmaps. Here, the hardware threads **1004-1-1**, **1004-3-1** and **1004-4-2** respectively write "1" to the bitmaps respectively allocated to the local hardware threads.

Hereinafter, the hardware threads **1004-1-2**, **1004-2-1**, **1004-2-2**, **1004-3-2** and **1004-4-1** arrive at the barrier synchronization point, and respectively write "1" to the bitmaps allocated to the local hardware threads.

In FIG. **1**C, the barrier synchronization mechanism **1003** changes the barrier state **1005** to "1" upon detecting that all the bitmaps are written to "1".

Each of the hardware threads **1004** verifies that the barrier state **1005** has become equal to the written value (namely, "1") of the bitmap, and resumes the process up to the next barrier synchronization point.

Conventionally, the barrier synchronization is implemented by an centralized barrier synchronization management mechanism.

The centralized barrier synchronization management mechanism has a problem such that, as the number of threads for which barrier synchronization is performed increases, the degree of complexity of the barrier synchronization management mechanism grows, the degree of realization of the mechanism decreases, and the number of threads—requested to be simultaneously processed grows, leading to a longer processing time.

[Patent Document 1] Japanese Laid-open Patent Publication No. 2006-259821

[Patent Document 2] Japanese National Publication of International Patent Application No. 2004-529414

[Non-patent Document 1] "Evaluation of Barrier Synchronization Mechanism Considering Hierarchical Processor Grouping", Kaito YAMADA, et al., IEICE Technical Report, Vol. 108, No. 28, ICD2008-20, pp. 19-24, May, 2008.

SUMMARY

According to an aspect of the invention, an information processing device includes a plurality of barrier banks, and one or more processors including at least one of the plurality of barrier banks.

Each of the plurality of barrier banks includes one or more hardware threads configured to execute a thread, and a barrier synchronization mechanism configured to perform barrier synchronization of the plurality of barrier banks.

The barrier synchronization mechanisms include a bottom unit having a barrier state indicating whether or not the synchronization is complete and a bitmap indicating that each of the one or more hardware threads has arrived at a synchronization point, and a top unit having a non-arrival counter indicating the number of barrier banks yet to be synchronized among the plurality of barrier banks for which the barrier synchronization is to be performed.

The bottom unit checks the bitmap, and notifies the plurality of barrier banks of a bottom unit synchronization completion when all the one or more hardware threads have arrived at a barrier synchronization point.

The non-arrival counter decrements its value by 1 upon receipt of the bottom unit synchronization completion.

The top unit sets the barrier state to a value indicating the synchronization completion when the non-arrival counter decrements to 0.

The object and advantages of the invention will be realized and attained by means of the elements and combinations particularly pointed out in the claims.

It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory and are not restrictive of the invention.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1**A illustrates conventional synchronization within a barrier bank.

FIG. **1**B illustrates the conventional synchronization within the barrier bank.

FIG. **1**C illustrates the conventional synchronization within the barrier bank.

FIG. **2** illustrates a configuration of a server according to an embodiment.

FIG. **3** illustrates a configuration of a CPU according to a first embodiment.

FIG. **4**A illustrates synchronization among barrier banks according to the first embodiment.

FIG. **4**B illustrates the synchronization among barrier banks according to the first embodiment.

FIG. **4**C illustrates the synchronization among barrier banks according to the first embodiment.

FIG. **5** illustrates a configuration of a CPU according to a second embodiment.

FIG. **6** illustrates a notification of barrier synchronization completion.

FIGS. **7**A and **7**B illustrate the notification of barrier synchronization completion.

FIGS. **8**A to **8**D illustrate synchronization among barrier banks according to a second embodiment.

FIGS. **9**A to **9**D illustrate the synchronization among barrier banks according to the second embodiment.

FIGS. **10**A to **10**D illustrates the synchronization among barrier banks according to the second embodiment.

FIGS. **11**A to **11**D illustrate the synchronization among barrier banks according to the second embodiment.

FIGS. **12**A to **12**D illustrates the synchronization among barrier banks according to the second embodiment.

FIG. **13** illustrates a configuration of a CPU according to a third embodiment.

FIG. **14** illustrates synchronization among barrier banks according to the third embodiment.

FIGS. **15**A and **15**B illustrate the synchronization among barrier banks according to the third embodiment.

FIGS. **16**A and **16**B illustrate the synchronization among barrier banks according to the third embodiment.

FIGS. **17**A and **17**B illustrate the synchronization among barrier banks according to the third embodiment.

FIGS. **18**A and **18**B illustrate the synchronization among barrier banks according to the third embodiment.

FIG. **19**A illustrates a configuration of a barrier synchronization mechanism according to the third embodiment.

FIG. **19**B illustrates a configuration of the barrier synchronization mechanism according to the third embodiment.

FIG. **19**C illustrates a configuration of the barrier synchronization mechanism according to the third embodiment.

FIG. **20** illustrates a configuration of a CPU according to a fourth embodiment.

FIG. **21**A illustrates a first setting example of a barrier synchronization mechanism according to the fourth embodiment.

FIG. **21**B illustrates a second setting example of the barrier synchronization mechanism according to the fourth embodiment.

FIG. **21**C illustrates a third setting example of the barrier synchronization mechanism according to the fourth embodiment.

FIG. **22**A illustrates barrier synchronization in the server according to the embodiments.

FIG. **22**B illustrates barrier synchronization in the server according to the embodiments.

FIG. **22**C illustrates barrier synchronization in the server according to the embodiments.

DESCRIPTION OF EMBODIMENTS

Embodiments are described below with reference to the drawings.

FIG. **2** illustrates a configuration of a server according to an embodiment.

The server **101** includes system boards **201**-*i* (i=1 to 4) and a switch **301**. The server **101** is one example of an information processing device (computer). A configuration of the server **101** is common in the following embodiments.

The system boards **201**-*i* are interconnected by communication paths via the switch **301**.

The system boards **201**-*i* respectively include CPUs **401**-*i*-*j* (j=1 to 4).

The CPUs **401**-*i*-*j* included in the same system board **201**-*i* are interconnected by a bus.

Each of the CPUs **401** includes one or more processor cores, each of which has one or more hardware threads.

First Embodiment

A first embodiment refers to synchronization of barrier banks of two hierarchies.

FIG. **3** illustrates a configuration of a CPU according to the first embodiment.

A CPU **501** corresponds to each of the CPUs **401** of FIG. **2**.

The CPU **501** includes processor cores **521**-*a* (a=1 to 4) and a barrier synchronization mechanism **531**. Moreover, the processor cores **521**-*a* and the barrier synchronization mechanism **531** are included in a barrier bank **511**, which is a minimum unit of barrier bank synchronization. The processor cores **521**-*a* and the barrier synchronization mechanism **531** are interconnected by a bus.

The processor cores **521**-*a* respectively have a simultaneous multi-threading function, and have hardware threads **522**-*a*-*b* (b=1, 2) for executing a thread.

In FIG. **3**, one processor core provides two hardware threads. Software (such as an operating system (OS)) that issues a software thread handles each of the hardware threads **522**-*a*-*b* as a logical CPU (virtual CPU).

The hardware threads **522** respectively execute a thread, read a top unit barrier state **552** when a corresponding hardware thread has arrived at a barrier synchronization point, and write a value obtained by inverting the read value to an allocated bitmap.

Moreover, the hardware threads **522** respectively check the top unit barrier state **552** with polling, determine that the synchronization is complete if the top unit barrier state **552** is equal to the value written to the bitmap, and execute the thread up to the next barrier synchronization point.

The barrier synchronization mechanism **531** controls the barrier synchronization, and is implemented, for example, with a hardware circuit and a processor.

The barrier synchronization mechanism **531** includes a bottom unit **541** and a top unit **551**.

The bottom unit **541** includes a bottom unit barrier state **542** and a bitmap group **543**.

The bottom unit barrier state **542** is information used to control the barrier synchronization. The bottom unit barrier state is "0" or "1".

The bitmap group **543** includes a plurality of bitmaps. Each of the bitmaps is information indicating that a corresponding hardware thread **522** has arrived at a barrier synchronization point. The same number of bitmaps are prepared by as the number of hardware threads **522** within the barrier bank **511**, and are respectively allocated to the hardware threads **522**. Namely, each of the bitmaps indicates that the allocated hardware thread **522** has arrived at a barrier synchronization point. A value of each of the bitmaps is "0" or "1".

The bottom unit **541** inverts the value of the bottom unit barrier state **542** if values of the all bitmaps of the bitmap group **543** become equal and different from the bottom unit barrier state **542**. Namely, the bottom unit barrier state **542** become equal to the values of the bitmaps of the bitmap group **543**. The bottom unit **541** transmits (broadcasts) bottom unit barrier synchronization completion to barrier synchronization mechanisms **531** within a specified range.

The top unit **551** includes a top unit barrier state **552**, a top unit non-arrival counter **553**, and a top unit expectation counter **554**.

The top unit barrier state **552** is information used to control the barrier synchronization. The top unit barrier state **552** indicates whether or not synchronization among all barrier banks for which barrier synchronization is to be performed is complete. The top unit barrier state **552** is "0" or "1". In FIG. **3**, the top unit barrier state **552** is "0".

The top unit non-arrival counter **553** counts the number of barrier banks that have not been synchronized (namely, all the hardware threads have not arrived at a barrier synchronization point within a barrier) bank among barrier banks to be synchronized, and holds the counted value. The top unit non-arrival counter **553** decrements its value by 1 upon receipt of the bottom unit barrier synchronization completion. The top unit non-arrival counter **553** is reset to the value of the top unit expectation counter **554** if the top unit non-arrival counter **553** decrements to "0".

The top unit expectation counter **554** is information indicating the number of barrier banks to be synchronized and holds its value.

The top unit **551** checks the top unit non-arrival counter **553**, and inverts the value of the top unit barrier state **552** upon detecting that the top unit non-arrival counter **553** is "0".

FIGS. **4**A to **4**C illustrate synchronization among barrier banks according to the first embodiment.

FIG. **4**A illustrates an initial state, FIG. **4**B illustrates synchronization being performed, and FIG. **4**C illustrates completion of the synchronization.

FIG. **4** explains a process of synchronization among four barrier banks.

In the first embodiment, barrier synchronization of two hierarchies is performed.

Four barrier synchronization mechanisms **531**-*i* (i=1 to 4) of FIG. **4** respectively belong to different barrier banks. Note that the barrier banks may be present within the same CPU or in different CPUs.

Each of the barrier banks of FIG. **4** is similar to the barrier bank **511** of FIG. **3**. For simplification of the drawing, FIG. **4** illustrates only the barrier synchronization mechanisms **531**-*i* within the barrier banks, and does not illustrate processor cores.

Each of the barrier synchronization mechanisms **531**-*i* includes a bottom unit **541**-*i* and a top unit **551**-*i*.

The bottom unit **541**-*i* includes a bottom unit barrier state **542**-*i* and a bitmap group **543**-*i*.

The top unit **551**-*i* includes a top unit barrier state **552**-*i*, a top unit non-arrival counter **553**-*i*, and a top unit expectation counter **554**-*i*.

The barrier synchronization mechanisms **531**-*i*, the bottom unit **541**-*i*, the top unit **551**-*i*, the bottom unit barrier state **542**-*i*, the bitmap group **543**-*i*, the top unit barrier state **552**-*i*, the top unit non-arrival counter **553**-*i*, and the top unit expectation counter **554**-*i* illustrated in FIG. **4**, respectively correspond to the barrier synchronization mechanism **531**, the bottom unit **541**, the top unit **551**, the bottom unit barrier state **542**, the bitmap group **543**, the top unit barrier state **552**, the top unit non-arrival counter **553** and the top unit expectation counter **554** illustrated in FIG. **3**.

In the initial state of FIG. **4**A, the bottom unit barrier state **542**-*i*, the top unit barrier state **552**-*i* and the bitmaps of the bitmap group **543**-*i* are "0". Moreover, the top unit non-arrival counter **553**-*i* and the top unit expectation counter **554**-*i* are "4".

Threads start to be executed respectively in the barrier banks in the initial state of FIG. **4**A.

Assume that all the bitmaps of the bitmap group **543-1** have changed to "1" in FIG. **4**B.

The bottom unit **541-1** detects that all the bitmaps are "1", and sets the bottom unit barrier state **542-1** to "1". Then, the bottom unit **541-1** transmits (broadcasts) bottom unit barrier synchronization completion to all the barrier banks for which barrier synchronization is to be performed. The bottom unit barrier synchronization completion indicates that the synchronization within the barrier bank is complete.

The top unit non-arrival counter **553**-*i* that has received the bottom unit barrier synchronization completion decrements its value by 1. As a result, the top unit non-arrival counter **553**-*i* decrements to "3" as illustrated in FIG. **4**B.

Similarly, all the bitmaps of the bitmap groups **543-2** and **543-4** have been changed to "1", and the bottom units **541-2** and **542-4** broadcast the bottom unit barrier synchronization completion to all the barrier banks for which the barrier synchronization is to be performed, so that the top unit non-arrival counter **553**-*i* decrements its value.

In FIG. **4**C, all the bitmaps of the bitmap group **543-3** have lastly changed to "1", and the bottom unit **541-3** broadcasts bottom unit barrier synchronization completion to all the barrier banks for which the barrier synchronization is to be performed, so that the top unit non-arrival counter **553**-*i* decrements to "0".

The top unit **551**-*i* checks the top unit non-arrival counter **553**-*i*, and inverts the value of the top unit barrier state **552**-*i* upon detecting that the top unit non-arrival counter **553**-*i* is "0". Here, the top unit **551**-*i* changes the top unit barrier state **552**-*i* from "0" to "1".

Since the top unit non-arrival counter **553**-*i* decrements to "0", the value of the top unit non-arrival counter **553**-*i* is reset to the same value as the top unit expectation counter **554**-*i*. Consequently, the top unit non-arrival counter **553**-*i* is again changed to "4".

Hardware threads connected to the barrier synchronization mechanism **531**-*i* check the top unit barrier state **552**-*i* via polling, determine that the entire barrier synchronization is complete since the value of the top unit barrier state **552**-*i* becomes equal to the values written to the bitmaps, and execute the thread up to the next barrier synchronization point.

The barrier synchronization mechanism **531**-*i* broadcasts the bottom unit synchronization completion to all the barrier synchronization mechanisms **531**-*i*, and all the top unit **551**-*i* of the barrier synchronization mechanisms **531**-*i* performs the same operation. Accordingly, whichever barrier synchronization mechanism is synchronized last, the synchronization completion can be reported to all the barrier synchronization mechanisms in the shortest communication time.

With the barrier synchronization mechanism according to the first embodiment, synchronization of barrier banks can be implemented with a simple configuration.

With the barrier synchronization mechanism according to the first embodiment, each barrier synchronization mechanism processes synchronization completion of hardware threads within a barrier bank to which the local barrier synchronization mechanism belongs, and processes a notification of barrier synchronization completion of other barrier bank synchronization mechanisms. As a result, a load is lightened compared with a conventional centralized barrier synchronization management mechanism, and thereby the length of processing time can be reduced.

If bitmaps are used for the top unit **541** similarly to the bottom unit **551**, the number of requested resources also grows with an increase in the number of barrier banks to be synchronized.

With the barrier synchronization mechanism according to the first embodiment, a counter is used in a top unit, whereby the number of resources can be prevented from being increased even if the number of barrier banks to be synchronized grows.

Second Embodiment

A second embodiment refers to synchronization among barrier banks of three hierarchies.

FIG. **5** illustrates a configuration of a CPU according to the second embodiment.

The CPU **601** corresponds to the CPU **401** of FIG. **2**.

The CPU **601** includes processor cores **621**-*a* (a=1 to 4) and a barrier synchronization mechanism **631**. Moreover, the processor cores **621**-*a* and the barrier synchronization mechanism **631** are included in a barrier bank **611**, which is a minimum unit of barrier bank synchronization. The processor cores **621**-*a* and the barrier synchronization mechanism **631** are interconnected by a bus.

Each of the processor cores **621**-*a* has a simultaneous multi-threading function, and includes hardware threads **622**-*a*-*b* (b=1, 2) for executing a thread.

In FIG. **5**, one processor core provides two hardware threads. Software (such as an operating system (OS)) for issuing a software thread handles each of the hardware threads **622**-*a*-*b* as a logical CPU (virtual CPU).

The hardware threads **622** respectively execute a thread, read a shared unit barrier state **642** when the corresponding hardware thread has arrived at a barrier synchronization point, and write a value obtained by inverting the read value to an corresponding bitmap **653**.

Additionally, the hardware threads **622** respectively check the shared unit barrier state **642** via polling, determine that the synchronization is complete if the value of the shared unit barrier state **642** is equal to the value written to the bitmap **653**, and execute the thread up to the next barrier synchronization point.

The barrier synchronization mechanism **631** controls the barrier synchronization, and is implemented, for example, with a hardware circuit and a processor.

The barrier synchronization mechanism **631** includes a shared unit **641**, a bottom unit **651**, a middle unit **661**, and a top unit **671**.

The shared unit **641** includes the shared unit barrier state **642**, a BANKID **643**, and a SYNCID **644**.

The shared unit barrier state **642** is information used to control the barrier synchronization. The shared unit barrier state **642** is information indicating whether or not the synchronization of all barrier banks for which the barrier synchronization is to be performed is complete. The shared unit barrier state **642** is "0" or "1".

The BANKID **643** is an identifier (ID) for identifying the barrier synchronization mechanism **631**.

The SYNCID **644** is an identifier (ID) for identifying a group to which the barrier synchronization mechanism **631** belongs.

The bottom unit **651** includes a bottom unit barrier state **652**, a bitmap group **653**, a bottom unit target ID **654**, and a bottom unit target mask **655**.

The bottom unit barrier state **652** is information used to control the barrier synchronization. The bottom unit barrier state **652** is "0" or "1".

The bitmap group **653** includes a plurality of bitmaps. Each of the bitmaps is information indicating that a corresponding hardware thread **622** has arrived at a barrier synchronization point. The same number of bitmaps are prepared as the number of hardware threads **622** within the barrier bank **611**, and respectively allocated to the hardware threads **622**. Namely, each of the bitmaps indicates that the allocated hardware thread **622** has arrived at a barrier synchronization point. The value of each of the bitmaps is "0" or "1".

The bottom unit target ID **654** is information indicating a barrier synchronization mechanism to which the bottom unit **651** broadcasts bottom unit barrier synchronization completion.

The bottom unit target mask **655** is information for specifying a position of a don't-care bit for the bottom unit target ID **654**. Namely, the bottom unit target mask **655** indicates a position of a bit that can take an arbitrary value in the bottom unit target ID **654**.

The bottom unit **651** inverts the value of the bottom unit barrier state **652** if values of all the bitmaps of the bitmap group **653** become equal and different from the bottom unit barrier state **652**. Namely, the value of the bottom unit barrier state **652** becomes equal to the value of the bitmaps of the bitmap group **653**. Then, the bottom unit **651** broadcasts bottom unit barrier synchronization completion to a barrier synchronization mechanism specified using the bottom unit target ID **654** and the bottom unit target mask **655**. If a SYNCID **644** is set, the bottom unit **651** adds the SYNCID **644** to the bottom unit barrier synchronization completion, and broadcasts the bottom unit barrier synchronization completion.

The middle unit **661** includes a middle unit non-arrival counter **662**, a middle unit expectation counter **663**, a middle unit target ID **664**, and a middle unit target mask **665**.

The middle unit non-arrival counter **662** counts the number of barrier synchronization mechanisms that have not transmitted bottom unit barrier synchronization completion among barrier synchronization mechanisms for which the barrier synchronization is checked by the middle unit **661**, and holds the counted value. The middle unit non-arrival counter **662** decrements its value by 1 upon receipt of the bottom unit barrier synchronization completion.

The middle unit expectation counter **663** is information indicating the number of barrier synchronization mechanisms for which the barrier synchronization is checked by the middle unit **661** and holds its value.

The middle unit target ID **664** is information indicating a barrier synchronization mechanism to which the middle unit **661** broadcasts barrier synchronization completion.

The middle unit target mask **665** is information for specifying a position of a don't-care bit for the middle unit target ID **664**. Namely, the middle unit target mask **665** indicates a position of a bit that can take an arbitrary value in the middle unit target ID **664**.

If the middle unit non-arrival counter **662** decrements to "0", the middle unit **661** broadcasts middle unit barrier synchronization completion to barrier synchronization mechanisms specified using the middle unit target ID **664** and the middle unit target mask **665**. Moreover, the middle unit **661** resets the value of the middle unit non-arrival counter **662** to that of the middle unit expectation counter **663** if the middle unit non-arrival counter **662** decrements to "0".

The top unit **671** includes a top unit non-arrival counter **672** and a top unit expectation counter **673**.

The top unit non-arrival counter **672** counts the number of barrier synchronization mechanisms that have not transmitted middle unit barrier synchronization completion among barrier synchronization mechanisms for which the barrier synchronization is checked by the top unit **671**, and holds the counted value. The top unit non-arrival counter **672** decrements its value by 1 upon receipt of the middle unit barrier synchronization completion.

The top unit non-arrival counter **672** decrements its value by 1 if an added SYNCID matches a SYNCID **644** when the SYNCID is added to the middle unit barrier synchronization completion. The top unit non-arrival counter **672** does not decrement its value if the added SYNCID does not match the SYNCID **644** when the SYNCID is added to the middle unit barrier synchronization completion. Namely, the top unit non-arrival counter **672** executes a process by regarding the middle unit barrier synchronization completion as a valid or invalid signal depending on whether or not the SYNCID added to the middle unit barrier synchronization completion matches the SYNCID **644**.

The top unit expectation counter **673** is information indicating the number of barrier synchronization mechanisms the barrier synchronization of which is checked by the top unit **671** and hold its value.

The top unit **671** inverts the value of the shared unit barrier state **642** if the top unit non-arrival counter **672** decrements to "0". Moreover, the top unit **671** resets the value of the top unit non-arrival counter **672** to that of the top unit expectation counter **673** if the top unit non-arrival counter **672** decrements to "0".

Here, specification of a broadcasting range using a target ID, a target mask, and a SYNCID is described. The target ID and the target mask, which are described here, are the bottom unit target ID **654** and the bottom unit target mask **655**, or the middle unit target ID **664** and the middle unit target mask **665**. A notification of barrier synchronization completion is made by the bottom unit **651** or the middle unit **661**.

FIGS. **6**, **7**A, and **7**B illustrate the notification of the barrier synchronization completion.

In FIGS. **6**, **7**A, and **7**B, 32 barrier synchronization mechanisms 0xk (k=00 to 1f) are present.

A BANKID of each of the barrier synchronization mechanisms 0xk is 0xk. For example, the BANKID of the barrier synchronization mechanism 0x00 is 0x00. Note that "0x" indicates hexadecimal notation. For example, if 0x00 is represented in binary notation, it is 0000_0000.

Here, a case where the barrier synchronization mechanism 0x00 broadcasts the barrier synchronization completion is described.

The barrier synchronization mechanism 0x00 broadcasts the barrier synchronization completion to barrier synchronization mechanisms specified using a target ID and a target mask.

Assume that the target ID and the target mask are respectively set to 0x00 and 0x14 in the barrier synchronization mechanism 0x00.

If the target ID 0x00 were represented in binary notation, it would be 0000_0000.

If the target mask 0x14 were represented in binary notation, it would be 0001_0100. Namely, this indicates that higher-order fourth and sixth bits of the target ID can take an arbitrary value.

The barrier synchronization mechanism 0x00 calculates a BANKID of barrier synchronization mechanisms (broadcasting range), to which the barrier synchronization completion is broadcast, with a target ID and a target mask.

Since the target ID and the target mask are respectively 0000_0000 and 0001_0100, the barrier synchronization mechanism 0x00 calculates all combinations where the higher-order fourth and sixth bits of the target ID=0000_0000 are arbitrary values.

As a result, 0000_0000, 0000_0100, 0001_0000 and 0000_0100 are calculated. If these results were represented in hexadecimal notation, they would be 0x00, 0x04, 0x10 and 0x14.

Namely, the barrier synchronization mechanisms to which the barrier synchronization completion is broadcast are the barrier synchronization mechanisms 0x00, 0x04, 0x10 and 0x14.

Accordingly, the barrier synchronization mechanism 0x00 broadcasts the barrier synchronization completion to the barrier synchronization mechanisms 0x00, 0x04, 0x10 and 0x14.

If IDs of destinations to which the barrier synchronization completion is reported are managed by using a list, the number of requested resources grows with an increase in the number of barrier banks to which the barrier synchronization completion is reported. By using a target ID and a target mask as described above, the number of resources can be prevented from being increased.

If a destination can be specified using an ID represented in n bits, a broadcasting range is set with two values such as an n-bit target ID and an n-bit target mask.

With this method, an arbitrary set of barrier banks may not be configured, although 2^m (0<=m<=n) barrier synchronization mechanisms can be specified as a broadcasting range.

A notification of barrier synchronization completion using a SYNCID is described as a method for configuring an arbitrary set of barrier banks.

A case where the barrier synchronization mechanism 0x04 broadcasts the barrier synchronization completion is described in FIG. **7**A.

The barrier synchronization mechanism 0x04 broadcasts the barrier synchronization completion to barrier synchronization mechanisms specified using a target ID and a target mask.

Assume that the target ID and the target mask are respectively set to 0x04 and 0x0b in the barrier synchronization mechanism 0x04.

Additionally, the barrier synchronization mechanisms 0x04, 0x05, 0x06, 0x0c, 0x0d and 0x0e have 0x11 as a SYNCID. The barrier synchronization mechanisms 0x07 and 0x0f have 0x00 as a SYNCID. Namely, the barrier synchronization mechanisms 0x04, 0x05, 0x06, 0x0c, 0x0d and 0x0e are set as a first set of barrier banks, whereas the barrier synchronization mechanisms 0x07 and 0x0f are set as a second set of barrier banks.

If the target ID 0x04 were represented in binary notation, it would be 0000_0100.

If the target mask 0x0b were represented in binary notation, it would be 0000_1011. Namely, this indicates that higher-order fifth, seventh and eighth bits of the target ID can take an arbitrary value.

The barrier synchronization mechanism 0x04 calculates a BANKID of the barrier synchronization mechanisms (broadcasting range) to which the barrier synchronization mechanism is broadcast, with a target ID and a target mask.

Since the target ID and the target mask are respectively 0000_0100 and 0000_1011, the barrier synchronization mechanism 0x04 calculates all combinations where higher-order fifth, seventh and eighth bits of the target ID=0000_0100 are arbitrary values.

As a result, 0000_0100, 0000_0101, 0000_0110, 0000_0111, 0000_1100, 0000_1101, 0000_1110 and 0000_1111 are calculated. If these results were represented in hexadecimal notation, they would be 0x04, 0x05, 0x06, 0x07, 0x0c, 0x0d, 0x0e and 0x0f.

Namely, the barrier synchronization mechanisms to which the barrier synchronization completion is broadcast are the barrier synchronization mechanisms 0x04, 0x05, 0x06, 0x07, 0x0c, 0x0d, 0x0e and 0x0f.

Accordingly, the barrier synchronization mechanism 0x04 broadcasts the barrier synchronization completion to which 0x11 is added as a SYNCID to the barrier synchronization mechanisms 0x04, 0x05, 0x06, 0x07, 0x0c, 0x0d, 0x0e and 0x0f.

The barrier synchronization mechanisms that have received the barrier synchronization completion respectively make a comparison between a local SYNCID and the SYNCID added to the barrier synchronization completion. The barrier synchronization mechanisms respectively execute a process by regarding the barrier synchronization completion as a valid signal if the SYNCIDs match, or executes a process by regarding the barrier synchronization completion as an invalid signal if the SYNCIDs do not match.

In FIGS. **7**A and **7**B, the barrier synchronization mechanisms 0x04, 0x05, 0x06, 0x0c, 0x0d and 0x0e execute a process (for example, decrementing the non-arrival counter) by regarding the barrier synchronization completion as a valid signal since the local SYNCID and the SYNCID added to the barrier synchronization completion match. In contrast, the barrier synchronization mechanisms 0x07 and 0x0f execute a process (for example, ignoring the notification of barrier synchronization completion and not decrementing the non-arrival counter) by regarding the barrier synchronization completion as an invalid signal since the local SYNCID and the SYNCID added to the barrier synchronization completion do not match.

As described above, valid barrier synchronization completion can be broadcast to an arbitrary set of barrier banks by using a target ID, a target mask, and a SYNCID.

The above described calculation of destinations of the barrier synchronization completion by using a target ID and a target mask is adopted similarly in the other embodiments.

FIGS. **8**A to **8**D, **9**A to **9**D, **10**A to **10**D, **11**A to **11**D, and **12**A to **12**D illustrate synchronization among barrier banks according to the second embodiment.

FIGS. **8**A to **8**D illustrate an initial state, FIGS. **9**A to **9**D, **10**A to **10**D, and **11**A to **11**D illustrate synchronization being performed, and FIGS. **12**A to **12**D illustrates completion of the synchronization.

FIGS. **8**A to **8**D, **9**A to **9**D, **10**A to **10**D, **11**A to **11**D, and **12**A to **12**D explain a process of synchronization among 16 barrier banks.

The 16 barrier synchronization mechanisms **631**-*m* (m=00 to 0f) of FIGS. **8**A to **8**D, **9**A to **9**D, **10**A to **10**D, **11**A to **11**D, and **12**A to **12**D respectively belong to different barrier banks. The barrier banks may be present within the same CPU or in different CPUs.

Each of the barrier banks of FIGS. **8**A to **8**D, **9**A to **9**D, **10**A to **10**D, **11**A to **11**D, and **12**A to **12**D is similar to the barrier bank **611** of FIG. **5**. For simplification in the drawing, FIGS. **8**A to **8**D, **9**A to **9**D, **10**A to **10**D, **11**A to **11**D, and **12**A to **12**D illustrate only the barrier synchronization mechanisms **631**-*m* within the barrier banks, and does not illustrate processor cores.

Additionally, in FIGS. **8**A to **8**D, **9**A to **9**D, **10**A to **10**D, **11**A to **11**D, and **12**A to **12**D, four second-hierarchy groups are set for every four barrier banks. In FIGS. **8**A to **8**D, **9**A to **9**D, **10**A to **10**D, **11**A to **11**D, and **12**A to **12**D, the barrier synchronization mechanisms of the first second-hierarchy group are the barrier synchronization mechanisms **631-00** to **631-03**, the barrier synchronization mechanisms of the second second-hierarchy group are the barrier synchronization mechanisms **631-04** to **631-07**, the barrier synchronization mechanisms of the third second-hierarchy groups are the barrier synchronization mechanisms **631-08** to **631-0***b*, and the barrier synchronization mechanisms of the fourth second-hierarchy group are the barrier synchronization mechanisms **631-0***c* to **631-0***f*.

Each of the barrier synchronization mechanisms **631**-*m* includes a shared unit **641**-*m*, a bottom unit **651**-*m*, a middle unit **661**-*m*, and a top unit **671**-*m*.

The shared unit **641**-*m* includes a shared unit barrier state **642**-*m*, a BANKID **643**-*m*, and a SYNCID **644**-*m*.

The bottom unit **651**-*m* includes a bottom unit barrier state **652**-*m*, a bitmap group **653**-*m*, a bottom unit target ID **654**-*m*, and a bottom unit target mask **655**-*m*.

The middle unit **661**-*m* includes a middle unit non-arrival counter **662**-*m*, a middle unit expectation counter **663**-*m*, a middle unit target ID **664**-*m*, and a middle unit target mask **665**-*m*.

The top unit **671**-*m* includes a top unit non-arrival counter **672**-*m* and a top unit expectation counter **673**-*m*.

The barrier synchronization mechanism **631**-*m*, the shared unit **641**-*m*, the bottom unit **651**-*m*, the middle unit **661**-*m*, the top unit **671**-*m*, the shared unit barrier state **642**-*m*, the BANKID **643**-*m*, the SYNCID **644**-*m*, the bottom unit barrier state **652**-*m*, the bitmap group **653**-*m*, the bottom unit target ID **654**-*m*, the bottom unit target mask **655**-*m*, the middle unit non-arrival counter **662**-*m*, the middle unit expectation counter **663**-*m*, the middle unit target ID **664**-*m*, the middle unit target mask **665**-*m*, the top unit non-arrival counter **672**-*m*, and the top unit expectation counter **673**-*m* illustrated in FIGS. **8**A to **8**D, **9**A to **9**D, **10**A to **10**D, **11**A to **11**D, and **12**A to **12**D, respectively correspond to the barrier synchronization mechanism **631**, the shared unit **641**, the bottom unit **651**, the middle unit **661**, the top unit **671**, the shared unit barrier state **642**, the BANKID **643**, the SYNCID **644**, the bottom unit barrier state **652**, the bitmap group **653**, the bottom unit target ID **654**, the bottom unit target mask **655**, the middle unit non-arrival counter **662**, the middle unit expectation counter **663**, the middle unit target ID **664**, the middle unit target mask **665**, the top unit non-arrival counter **672** and the top unit expectation counter **673** illustrated in FIG. **5**.

In the initial state illustrated in FIGS. **8**A to **8**D, the shared-unit barrier state **642**-*m* is 0.

Each BANKID **643**-*m* is set to 0xm.

Additionally, the SYNCID **644**-*m* is not set.

The bottom unit barrier state **652**-*m* is 0.

Each of bitmaps of the bitmap group **653**-*m* is 0.

The bottom unit target ID **654**-*m* is 0x00, and the bottom unit target mask **655**-*m* is 0x0c.

The middle unit non-arrival counters **662-0**, **662-04**, **662-08** and **662-0***c* are 16.

The middle unit non-arrival counters **662-01** to **662-03**, **662-05** to **662-07**, **662-09** to **662-0***b*, and **662-0***d* to **662-0***f* are not set.

The middle unit expectation counters **663-00**, **663-04**, **663-08** and **663-0***c* are 16.

The middle unit expectation counters **663-01** to **663-03**, **663-05** to **663-07**, **663-09** to **663-0***b*, **663-0***d* to **663-0***f* are not set.

The middle unit target IDs **664-00**, **664-04**, **664-08** and **664-0***c* are respectively 0x00, 0x04, 0x08 and 0x0c.

The middle unit target IDs **664-01** to **664-03**, **664-05** to **664-07**, **664-09** to **664-0***b* and **664-0***d* to **664-0***f* are not set.

The middle unit target masks **665-00**, **665-04**, **665-08** and **665-0***c* are 0x03.

The middle unit target masks **665-01** to **665-03**, **665-05** to **665-07**, **665-09** to **665-0***b*, **665-0***d* to **665-0***f* are not set.

The top unit non-arrival counter **672**-*m* is 1.

The top unit expectation counter **673**-*m* is 1.

The barrier synchronization mechanism **631** in which the middle unit non-arrival counter **662**, the middle unit expectation counter **663**, the middle unit target ID **664**, and the middle unit target mask **665** are set is referred to as a middle unit valid barrier bank.

The barrier synchronization mechanism **631** in which the middle unit non-arrival counter **662**, the middle unit expectation counter **663**, the middle unit target ID **664** and the middle unit target mask **665** are not set is referred to as a middle unit invalid barrier bank.

In FIGS. **8**A to **8**D, **9**A to **9**D, **10**A to **10**D, **11**A to **11**D, and **12**A to **12**D, the barrier synchronization mechanisms **631-00**, **631-04**, **631-08** and **631-0***c* are middle unit valid barrier banks, whereas the barrier synchronization mechanisms **631-01** to **631-03**, **631-05** to **631-07**, **631-09** to **631-0***b* and **631-0***d* to **631-0***f* are middle unit invalid barrier banks.

In FIGS. **9**A to **9**D, hardware threads connected to the barrier synchronization mechanisms **631**-*m* are executing a process.

Assume that all bitmaps of the bitmap group **653-01** become "1". Namely, assume that all hardware threads connected to the barrier synchronization mechanism **631-01** have arrived at a barrier synchronization point. The bottom unit **651-01** inverts the value of the bottom unit barrier state **652-01**, namely, changes the value to "1".

Then, the bottom unit **651-01** broadcasts bottom unit barrier synchronization completion to the middle units **661-00**, **661-04**, **661-08** and **661-0***c* of the barrier synchronization mechanisms **631-00**, **631-04**, **631-08** and **631-0***c*, which are specified using a bottom unit target ID **654-01** and a bottom unit target mask **655-01**.

The middle unit non-arrival counters **662-00**, **662-04**, **662-08** and **662-0***c*, which have received the bottom unit barrier synchronization completion, respectively decrement their value by 1.

As a result, the value of the middle unit non-arrival counters **662-00**, **662-04**, **662-08** and **662-0***c* decrements from "16" to "15".

Similarly, all bitmaps of the bitmap groups **653-00**, **653-02**, **653-04** to **653-0***f* change to "1", and the bottom unit barrier states **652-00**, **652-02** and **652-04** to **652-0***f* change to "1".

Then, the bottom units **651-00** and **651-02**, **651-04** to **651-0***f* respectively broadcast bottom unit barrier synchronization completion to the middle units **661-00**, **661-04**, **661-08** and **661-0***c*.

The middle unit non-arrival counters **662-00**, **662-04**, **662-08** and **662-0***c* respectively decrement their value by 1 for each reception of the bottom unit barrier synchronization completion.

In FIGS. **10**A to **10**D, all bitmaps of the bitmap group **653-03** lastly change to "1". The bottom unit **651-03** inverts the value of the bottom unit barrier state **652-03**, namely, changes the value to "1".

Then, the bottom unit **651-03** broadcasts bottom unit barrier synchronization completion to the middle units **661-00**, **661-04**, **661-08** and **661-0***c* of the barrier synchronization mechanisms **631-00**, **631-04**, **631-08** and **631-0***c*, which are specified using the bottom unit target ID **654-03** and the bottom unit target mask **655-03**.

The middle unit non-arrival counters **662-00**, **662-04**, **662-08** and **662-0***c*, which have received the bottom unit barrier synchronization completion, respectively decrement their value by 1.

As a result, the values of the middle unit non-arrival counters **662-00**, **662-04**, **662-08** and **662-0**C are decremented from "1" to "0".

In FIGS. **11**A to **11**D, the middle units **661-00**, **661-04**, **661-08** and **661-0***c* respectively broadcast middle unit barrier synchronization completion to the top unit **671** of the barrier synchronization mechanisms, which are specified using the middle unit target IDs **664-00**, **664-04**, **664-08**, **664-0***c* and the middle unit target masks **665-00**, **665-04**, **665-08** and **665-0***c*, upon detecting that the middle unit non-arrival counters **662-00**, **662-04**, **662-08** and **662-0***c* decrement to "0".

The middle unit **661-00** broadcasts the middle unit barrier synchronization completion to the top units **671-00** to **671-03** of the barrier bank synchronization mechanisms **631-00** to **631-03**, which are specified using the middle unit target ID **664-00** and the middle unit target mask **665-00**, upon detecting that the middle unit non-arrival counter **662-00** decrements to "0". Moreover, the middle unit non-arrival counter **662-00** resets the value of the middle unit non-arrival counter **662-00** to that of the middle unit expectation counter **653-00**.

The middle unit **661-04** broadcasts the middle unit barrier synchronization completion to the top units **671-04** to **671-07** of the barrier bank synchronization mechanisms **631-04** to **631-07**, which are specified using the middle unit target ID **664-04** and the middle unit target mask **665-04**, upon detecting that the middle unit non-arrival counter **662-04** decrements to "0". Moreover, the middle unit non-arrival counter **662-04** resets the value of the middle unit non-arrival counter **662-04** to that of the middle unit expectation counter **653-04**.

The middle unit **661-08** broadcasts the middle unit barrier synchronization completion to the top units **671-08** to **671-**

0*b* of the barrier bank synchronization mechanisms **631-08** to **631-0***b*, which are specified using the middle unit target ID **664-08** and the middle unit target mask **665-08**, upon detecting that the middle unit non-arrival counter **662-08** decrements to "0". Moreover, the middle unit non-arrival counter **662-08** resets the value of the middle unit non-arrival counter **662-08** to that of the middle unit expectation counter **653-08**.

The middle unit **661-0***c* broadcasts the middle unit barrier synchronization completion to the top units **671-0***c* to **671-0***f* the barrier bank synchronization mechanisms **631-0***c* to **631-0***f*, which are specified using the middle unit target ID **664-0***c* and the middle unit target mask **665-0***c*, upon detecting that the middle unit non-arrival counter **662-0***c* decrements to "0". Moreover, the middle unit non-arrival counter **662-0***c* resets the value of the middle unit non-arrival counter **662-0***c* to that of the middle unit expectation counter **653-0***c*.

The top unit non-arrival counter **672-***m* that has received the middle unit barrier synchronization completion decrements its value by 1. As a result, the value of the top unit non-arrival counter **672-***m* decrements from "1" to "0".

In FIGS. **12**A to **12**D, the top unit **671-***m* inverts the value of the shared unit barrier state **642-***m* upon detecting that the top unit non-arrival counter **672-***m* decrements to "0". As a result, the value of the shared unit barrier state **642-***m* changes from "0" to "1".

Additionally, the top unit non-arrival counter **672-***m* resets the value of the top unit non-arrival counter **672-***m* to that of the top unit expectation counter **673-***m*.

Hardware threads connected to the barrier synchronization mechanism **631-***m* respectively verify that the value of the shared unit barrier state **642-***m* becomes equal to the value (1) that the shared unit barrier state **642** writes to the bitmap, and execute the process up to the next barrier synchronization point.

With the barrier synchronization mechanism according to the second embodiment, synchronization among barrier banks can be implemented with a simple configuration.

With a conventional centralized barrier synchronization management mechanism, the number of communications that pass through a network grows with an increase in the number of processor cores for which barrier synchronization is performed, thereby causing network congestion.

Assuming that n=the total number of barrier banks in the barrier synchronization of two hierarchies in the first embodiment, n^2 communications occur. In contrast, the number of communications in the barrier synchronization of three hierarchies in the second embodiment is n*(m+1) if m=the number of barrier bank groups of the second hierarchy is assumed.

Therefore, the number of communications can be significantly reduced, whereby a network can be prevented from getting congested.

Third Embodiment

A third embodiment refers to synchronization among barrier banks of four hierarchies.

FIG. **13** illustrates a configuration of a CPU according to the third embodiment.

The CPU **701** corresponds to the CPU **401** of FIG. **2**.

The CPU **701** includes processor cores **721-***a* (a=1 to 4) and a barrier synchronization mechanism **731**. The processor cores **721-***a* and the barrier synchronization mechanism **731** are included in a barrier bank **711**, which is a minimum unit of barrier bank synchronization. The processor cores **721-***a* and the barrier synchronization mechanism **731** are interconnected by a bus.

Each of the processor cores **721-***a* has a simultaneous multi-threading function, and has hardware threads **722-***a-b* (b=1, 2) for executing a thread.

Since each of the hardware threads **722** has a function similar to the hardware thread **622** of FIG. **5**, their explanation is omitted.

The barrier synchronization mechanism **731** controls the barrier synchronization, and is implemented, for example, with a hardware circuit and a processor.

The barrier synchronization mechanism **731** includes a shared unit **741**, a bottom unit **751**, a middle unit **761** and a top unit **771**.

The shared unit **741** includes a shared unit barrier state **742**, a BANKID **743** and a SYNCID **744**.

Since the shared unit barrier state **742**, the BANKID **743** and the SYNCID **744** have a function similar to that of the shared unit barrier state **642**, the BANKID **643** and the SYNCID **644** illustrated in FIG. **5**, their explanations are omitted.

The bottom unit **751** includes a bottom unit barrier state **752**, a bitmap group **753**, a bottom unit target ID **754** and a bottom unit target mask **755**.

Since the bottom unit **751**, the bottom unit barrier state **752**, the bitmap group **753**, the bottom unit target ID **754** and the bottom unit target mask **755** have a function similar to that of the bottom unit barrier state **652**, the bitmap group **653**, the bottom unit target ID **654** and the bottom unit target mask **655** illustrated in FIG. **5**, their explanations are omitted.

The middle unit **761** includes a middle unit non-arrival counter **762**, a middle unit expectation counter **763**, a middle unit target ID **764**, a middle unit target mask **765**, and a middle unit destination hierarchy **766**.

The middle unit non-arrival counter **762** counts the number of barrier synchronization mechanisms that have not transmitted bottom unit barrier synchronization completion among barrier synchronization mechanisms for which the barrier synchronization is checked by the middle unit **761**, and holds the counted value. The middle unit non-arrival counter **762** decrements its value by 1 upon receipt of the bottom unit barrier synchronization completion. Moreover, the middle unit non-arrival counter **762** decrements its value by 1 upon receipt of the middle unit barrier synchronization completion to which TO_MIDDLE=1 is added.

The middle unit expectation counter **763** is information indicating the number of barrier synchronization mechanisms for which the barrier synchronization is checked by the middle unit **761** and holds its value.

The middle unit target ID **764** is information indicating a barrier synchronization mechanism to which the middle unit **761** broadcasts the barrier synchronization completion.

The middle unit target mask **765** is information for specifying a position of a don't-care bit for the middle unit target ID **764**. Namely, the middle unit target mask **765** indicates a position of a bit that can take an arbitrary value in the middle unit target ID **764**.

The middle unit destination hierarchy **766** indicates a processing unit (middle unit or top unit) for processing the received middle unit barrier synchronization completion. The middle unit destination hierarchy **766** is "1" or "0". "1" indicates that the middle unit **761** that has received the middle unit synchronization completion executes a process for the reception of the middle unit synchronization completion. "0" indicates that the top unit **771** that has received the middle unit synchronization completion executes a process for the reception of the middle unit synchronization completion. FIG. **14** and subsequent drawings illustrate “1” and “0” respectively as “MIDDLE” and “TOP”.

The middle unit **761** broadcasts the middle unit barrier synchronization completion to barrier synchronization mechanisms specified using a middle unit target ID **764** and a middle unit target mask **765** if the middle unit non-arrival counter **762** decrements to “0”. The middle unit **761** adds the value of the middle unit destination hierarchy **766** to the middle unit barrier synchronization completion. For example, the middle unit **761** adds TO_MIDDLE=1 to the middle unit barrier synchronization completion if the middle unit destination hierarchy **766** is “1”, or adds TO_MIDDLE=0 to the middle unit barrier synchronization completion if the middle unit destination hierarchy **766** is “0”. The middle unit **761** further adds a SYNCID **744** to the middle unit barrier synchronization completion if the SYNCID **744** is set.

Additionally, the middle unit **761** resets the value of the middle unit non-arrival counter **762** to that of the middle unit expectation counter **763** if the middle unit non-arrival counter **762** decrements to “0”.

The top unit **771** includes a top unit non-arrival counter **772** and a top unit expectation counter **773**.

The top unit non-arrival counter **772** counts the number of barrier synchronization mechanisms that have not transmitted middle unit barrier synchronization completion, to which TO_MIDDLE=0 is added, among barrier synchronization mechanisms for which the barrier synchronization is checked by the top unit **771**, and holds the counted value. The top unit non-arrival counter **722** decrements its value by 1 upon receipt of the middle unit barrier synchronization completion to which TO_MIDDLE=0 is added.

Additionally, the top unit non-arrival counter **772** decrements its value by 1 if an added SYNCID matches the SYNCID **744** when the SYNCID is added to the middle unit barrier synchronization completion to which TO_MIDDLE **0** is added. The top unit non-arrival counter **772** does not decrement its value if the added SYNCID does not match the SYNCID **744** when the SYNCID is added to the middle unit barrier synchronization completion to which TO_MIDDLE=0 is added. Namely, the top unit non-arrival counter **772** executes a process by regarding the middle unit barrier synchronization completion as a valid or invalid signal depending on whether or not the SYNCID added to the middle unit barrier synchronization completion matches the SYNCID **744**.

The top unit expectation counter **773** is information indicating the number of barrier synchronization mechanisms for which the barrier synchronization is checked by the top unit **771** and holds its value.

The top unit **771** inverts the value of the shared unit barrier state **742** if the top unit non-arrival counter **772** decrements to “0”. Moreover, the top unit **771** resets the value of the top unit non-arrival counter **772** to that of the top unit expectation counter **773** if the top unit non-arrival counter **772** decrements to “0”.

FIGS. **14**, **15**A, **15**B, **16**A, **16**B, **17**A, **17**B, **18**A, and **18**B illustrate synchronization among barrier banks according to the third embodiment.

FIG. **14** illustrates an initial state, FIGS. **15**A, **15**B, **16**A, **16**B, **17**A, and **17**B illustrate synchronization being performed, and FIGS. **18**A and **18**B illustrate completion of the synchronization.

FIGS. **14**, **15**A, **15**B, **16**A, **16**B, **17**A, **17**B, **18**A, and **18**B refer to a process of synchronization among 64 barrier banks.

The 64-barrier synchronization mechanisms **731**-*s* (s=00 to 3f) of FIGS. **14**, **15**A, **15**B, **16**A, **16**B, **17**A, **17**B, **18**A, and **18**B belong to different barrier banks. The barrier banks may be present within the same CPU or in different CPUs.

Each of the barrier banks of FIGS. **14**, **15**A, **15**B, **16**A, **16**B, **17**A, **17**B, **18**A, and **18**B is similar to the barrier bank **611** of FIG. **5**. For simplification of the drawing, FIGS. **14**, **15**A, **15**B, **16**A, **16**B, **17**A, **17**B, **18**A, and **18**B illustrate only the barrier synchronization mechanisms **731**-*s* within the barrier banks, and does not illustrate processor cores.

In FIGS. **14**, **15**A, **15**B, **16**A, **16**B, **17**A, **17**B, **18**A, and **18**B, four second-hierarchy groups are set for every 16 barrier banks. Moreover, eight third-hierarchy groups are set for every 8 barrier banks.

FIGS. **19**A to **19**C illustrate a configuration of the barrier synchronization mechanism according to the third embodiment.

The barrier synchronization mechanism illustrated in FIGS. **19**A to **19**C is that in the initial state illustrated in FIG. **14**.

FIG. **19**A illustrates a configuration of the barrier synchronization mechanisms **731**-*p* (p=01 to 03, 05 to 0b, 0d to 0f, 11 to 13, 15 to 1b, 1d to 1f, 21 to 23, 25 to 2b, 2d to 2f, 31 to 33, 35 to 3b and 3d to 3f).

The barrier synchronization mechanism **731**-*p* includes a shared unit **741**-*p*, a bottom unit **751**-*p*, a middle unit **761**-*p*, and a top unit **771**-*p*.

The shared unit **741**-*p* includes a shared unit barrier state **742**-*p*, a BANKID **743**-*p* and a SYNCID **744**-*p*.

The bottom unit **751**-*p* includes a bottom unit barrier state **752**-*p*, a bitmap group **753**-*p*, a bottom unit target ID **754**-*p*, and a bottom unit target mask **755**-*p*.

The middle unit **761**-*p* includes a middle unit non-arrival counter **762**-*p*, a middle unit expectation counter **763**-*p*, a middle unit target ID **764**-*p*, a middle unit target mask **765**-*p*, and a middle unit destination hierarchy **766**-*p*.

The top unit **771**-*p* includes a top unit non-arrival counter **772**-*p* and a top unit expectation counter **773**-*p*. The shared unit barrier state **742**-*p*, the BANKID **743**-*p*, the SYNCID **744**-*p*, the bottom unit barrier state **752**-*p*, the bitmap group **753**-*p*, the bottom unit target ID **754**-*p*, the bottom unit target mask **755**-*p*, the middle unit non-arrival counter **762**-*p*, the middle unit expectation counter **763**-*p*, the middle unit target ID **764**-*p*, the middle unit target mask **765**-*p*, the middle unit destination hierarchy **766**-*p*, the top unit non-arrival counter **772**-*p* and the top unit expectation counter **773**-*p* respectively correspond to the shared unit barrier state **742**, the BANKID **743**, the SYNCID **744**, the bottom unit barrier state **752**, the bitmap group **753**, the bottom unit target ID **754**, the bottom unit target mask **755**, the middle unit non-arrival counter **762**, the middle unit expectation counter **763**, the middle unit target ID **764**, the middle unit target mask **765**, the middle unit destination hierarchy **766**, the top unit non-arrival counter **772** and the top unit expectation counter **773** illustrated in FIG. **13**.

In an initial state, the shared unit barrier state **742**-*p* is “0”.

Each BANKID **743**-*p* is set to 0xp. The BANKID **743**-*p* (=0xp) possessed by the barrier synchronization mechanism **731**-*p* is also referred to as a local ID.

Additionally, the SYNCID **744**-*p* is not set.

The bottom unit barrier state **752**-*p* is “0”.

Each of the bitmaps of the bitmap group **753**-*p* is “0”.

The bottom unit target ID **754**-*p* is BANKID **743**-*p* & 0xf0, and the bottom unit target mask **755**-*p* is 0x00. “&”

indicates a logical AND. The BANKID **743**-*p* & 0xf0 is a logical AND between the value of the BANKID **743**-*p* and 0xf0.

The middle unit non-arrival counter **762**-*p* is not set.

The middle unit expectation counter **763**-*p* is not set.

The middle unit target ID **764**-*p* is not set.

The middle unit target mask **765**-*p* is not set.

The middle unit destination hierarchy **766**-*p* is not set.

The top unit non-arrival counter **672**-*p* is "1".

The top unit expectation counter **673**-*p* is "1".

The barrier synchronization mechanism **731**-*p* where the middle unit non-arrival counter **762**-*p*, the middle unit expectation counter **763**-*p*, the middle unit target ID **764**-*p*, the middle unit target mask **765**-*p*, and the middle unit destination hierarchy **766**-*p* are not set is referred to as a middle unit invalid barrier bank.

FIG. **19**B illustrates a configuration of the barrier synchronization mechanism **731**-*q* (q=00, 10, 20, 30).

The barrier synchronization mechanism **731**-*q* includes a shared unit **741**-*q*, a bottom unit **751**-*q*, a middle unit **761**-*q* and a top unit **771**-*q*.

The shared unit **741**-*q* includes a shared unit barrier state **742**-*q*, a BANKID **743**-*q* and a SYNCID **744**-*q*.

The bottom unit **751**-*q* includes a bottom unit barrier state **752**-*q*, a bitmap group **753**-*q*, a bottom unit target ID **754**-*q* and a bottom unit target mask **755**-*q*.

The middle unit **761**-*q* includes a middle unit non-arrival counter **762**-*q*, a middle unit expectation counter **763**-*q*, a middle unit target ID **764**-*q*, a middle unit target mask **765**-*q* and a middle unit destination hierarchy **766**-*q*.

The top unit **771**-*q* includes a top unit non-arrival counter **772**-*q* and a top unit expectation counter **773**-*q*.

The shared unit barrier state **742**-*q*, the BANKID **743**-*q*, the SYNCID **744**-*q*, the bottom unit barrier state **752**-*q*, the bitmap group **753**-*q*, the bottom unit target ID **754**-*q*, the bottom unit target mask **755**-*q*, the middle unit non-arrival counter **762**-*q*, the middle unit expectation counter **763**-*q*, the middle unit target ID **764**-*q*, the middle unit target mask **765**-*q*, the middle unit destination hierarchy **766**-*q*, the top unit non-arrival counter **772**-*q* and the top unit expectation counter **773**-*q* respectively correspond to the shared unit barrier state **742**, the BANKID **743**, the SYNCID **744**, the bottom unit barrier state **752**, the bitmap group **753**, the bottom unit target ID **754**, the bottom unit target mask **755**, the middle unit non-arrival counter **762**, the middle unit expectation counter **763**, the middle unit target ID **764**, the middle unit target mask **765**, the middle unit destination hierarchy **766**, the top unit non-arrival counter **772** and the top unit expectation counter **773** illustrated in FIG. **13**.

In an initial state, the shared unit barrier state **742**-*q* is "0".

Each BANKID **743**-*q* is set to 0xq. The BANKID **743**-*q* (=0xp) possessed by the barrier synchronization mechanism **731**-*q* is also referred to as a local ID.

Additionally, the SYNCID **744**-*q* is not set.

The bottom unit barrier state **752**-*q* is "0".

Each of the bitmaps of the bitmap group **753**-*q* is "0".

The bottom unit target ID **754**-*q* is BANKID **743**-*q* & 0xf0, and the bottom unit target mask **755**-*q* is 0x00.

The middle unit non-arrival counter **762**-*q* is 16.

The middle unit expectation counter **763**-*q* is 16.

The middle unit target ID **764**-*q* is 0x04.

The middle unit target mask **765**-*q* is 0x38.

The middle unit destination hierarchy **766**-*q* is "1".

The top unit non-arrival counter **672**-*q* is "1".

The top unit expectation counter **673**-*q* is "1".

FIG. **19**C illustrates a configuration of a barrier synchronization mechanism. **731**-*r* (r=04, 0c, 14, 1c, 24, 2c, 34, 3c).

The barrier synchronization mechanism **731**-*r* includes a shared unit **741**-*r*, a bottom unit **751**-*r*, a middle unit **761**-*r* and a top unit **771**-*r*.

The shared unit **741**-*r* includes a shared unit barrier state **742**-*r*, a BANKID **743**-*r* and a SYNCID **744**-*r*.

The bottom unit **751**-*r* includes a bottom unit barrier state **752**-*r*, a bitmap group **753**-*r*, a bottom unit target ID **754**-*r* and a bottom unit target mask **755**-*r*.

The middle unit **761**-*r* includes a middle unit non-arrival counter **762**-*r*, a middle unit expectation counter **763**-*r*, a middle unit target ID **764**-*r*, a middle unit target mask **765**-*r* and a middle unit destination hierarchy **766**-*r*.

The top unit **771**-*r* includes a top unit non-arrival counter **772**-*r* and a top unit expectation counter **773**-*r*.

The shared unit barrier state **742**-*r*, the BANKID **743**-*r*, the SYNCID **744**-*r*, the bottom unit barrier state **752**-*r*, the bitmap group **753**-*r*, the bottom unit target ID **754**-*r*, the bottom unit target mask **755**-*r*, the middle unit non-arrival counter **762**-*r*, the middle unit expectation counter **763**-*r*, the middle unit target ID **764**-*r*, the middle unit target mask **765**-*r*, the middle unit destination hierarchy **766**-*r*, the top unit non-arrival counter **772**-*r* and the top unit expectation counter **773**-*r* respectively correspond to the shared unit barrier state **742**, the BANKID **743**, the SYNCID **744**, the bottom unit barrier state **752**, the bitmap group **753**, the bottom unit target ID **754**, the bottom unit target mask **755**, the middle unit non-arrival counter **762**, the middle unit expectation counter **763**, the middle unit target ID **764**, the middle unit target mask **765**, the middle unit destination hierarchy **766**, the top unit non-arrival counter **772** and the top unit expectation counter **773** illustrated in FIG. **13**.

In an initial state, the shared unit barrier state **742**-*r* is "0".

Each BANKID **743**-*r* is set to 0xr. The BANKID **743**-*r* (=0xr) possessed by the barrier synchronization mechanism **731**-*r* is referred to also as a local ID.

Additionally, the SYNCID **744**-*r* is not set.

The bottom unit barrier state **752**-*r* is "0".

Each of the bitmaps of the bitmap group **753**-*r* is "0".

The bottom unit target ID **754**-*r* is BANKID **743**-*r* & 0xf0, and the bottom unit target mask **755**-*r* is 0x00.

The middle unit non-arrival counter **762**-*r* is 4.

The middle unit expectation counter **763**-*r* is 4.

The middle unit target ID **764**-*r* is 0xr. Namely, the value of the middle unit target ID **764***r* is equal to the BANKID **743**-*r*.

The middle unit target mask **765**-*r* is 0x07.

The middle unit destination hierarchy **766**-*r* is "0".

The top unit non-arrival counter **672**-*r* is "1".

The top unit expectation counter **673**-*r* is "1".

Firstly, in the initial state of FIG. **14**, hardware threads of each barrier bank start a process.

Assume that all the bitmaps of the bitmap group **753-02** of the barrier synchronization mechanism **731-02** have been changed to "1" and the bottom unit barrier state **752-02** have been changed from "0" to "1" as illustrated in an upper portion of FIGS. **15**A and **15**B.

The bottom unit **751-02** notifies the barrier synchronization mechanism **731-00** of bottom unit barrier synchronization completion.

The middle unit non-arrival counter **762-00** that has received the bottom unit barrier synchronization completion decrements its value by 1.

Assume that all the bitmaps of the bitmap groups **753-00** to **753-01**, **753-03** to **753-0***c*, **753-0***e* to **753-0***f* the barrier synchronization mechanisms **731-00** to **731-01**, **731-03** to **731-0***c*, **731-0***e* to **731-0***f* have been changed to "1", and the bottom unit barrier states **752-00** to **752-01**, **752-03** to **752-0***c* and **752-0***e* to **752-0***f* have been changed from "0" to "1" in a similar manner.

The bottom units **751-00** to **751-01**, **751-03** to **751-0***c* and **751-0** to **751-0***f* notify the barrier synchronization mechanism **731-00** of bottom unit barrier synchronization completion.

The middle unit non-arrival counter **762-00** decrements its value by 1 for each reception of the bottom unit barrier synchronization completion.

Assume that all the bitmaps of the bitmap group **753-0***d* of the barrier synchronization mechanism **731-0***d* have been changed to "1" and the bottom unit barrier state **752-0***d* have been changed from "0" to "1" as illustrated in a lower portion of FIGS. **15**A and **15**B.

The bottom unit **751-0***d* notifies the barrier synchronization mechanism **731-00** of the bottom unit barrier synchronization completion.

The middle unit non-arrival counter **762-00** that has received the bottom unit barrier synchronization completion decrements its value by 1. As a result, the value of the middle unit non-arrival counter **762-00** decrements to "0".

In FIGS. **16**A and **16**B, the middle unit **761-00** of the barrier synchronization mechanism **731-00** detects that the middle unit non-arrival counter **762-00** decrements to "0", and broadcasts middle unit synchronization completion to the barrier synchronization mechanism **731-***r*. Note that the middle unit **761-00** adds a destination hierarchy **766-00** (TO_MIDDLE=1) to the middle unit synchronization completion.

Additionally, the middle unit non-arrival counter **762-00** resets the middle unit non-arrival counter **762-00** to the value (16) of the middle unit expectation counter **763-00**.

The middle unit **761-***r* that has received the middle unit synchronization completion to which TO_MIDDLE=1 is added decrements the middle unit non-arrival counter **762-***r* by 1.

Assume that all bitmaps of the bitmap groups **753-10** to **753-3***f* of the barrier synchronization mechanisms **731-10** to **731-3***f* have changed to "1" and the bottom unit barrier states **752-10** to **752-3***f* have been changed from "0" to "1" in a similar manner.

The bottom units **751-10** to **751-1***f* notify the barrier synchronization mechanism **731-10** of bottom unit barrier synchronization completion.

The bottom units **751-20** to **751-2***f* notify the barrier synchronization mechanism **731-20** of bottom unit barrier synchronization completion.

The bottom units **751-30** to **751-3***f* notify the barrier synchronization mechanism **731-30** of bottom unit barrier synchronization completion.

The middle unit non-arrival counters **762-10**, **762-20** and **762-30** respectively decrement their value by 1 for each reception of the bottom unit barrier synchronization completion.

The middle units **761-10** and **761-20** of the barrier synchronization mechanisms **731-10** and **731-20** respectively detect that the middle unit non-arrival counters **762-10** and **762-20** decrement to "0", and broadcast the middle unit synchronization completion to the barrier synchronization mechanism **731-***r*. The middle units **761-10** and **761-20** respectively add destination hierarchies 766-10 and 766-20 (TO_MIDDLE=1) to the middle unit synchronization completion.

Additionally, the middle unit non-arrival counters **762-10** and **762-20** respectively reset the middle unit non-arrival counters **762-10** and **762-20** to the value (16) of the middle unit expectation counter **763-10** and **763-20**.

The middle unit **761-***r* decrements the middle unit non-arrival counter **762-***r* by 1 for each reception of the middle unit synchronization completion to which TO_MIDDLE=1 is added.

The middle unit **761-30** of the barrier synchronization mechanism **731-30** detects that the middle unit non-arrival counter **762-30** decrements to "0", and broadcasts middle unit synchronization completion to the barrier synchronization mechanism. **731-***r* in FIGS. **17**A and **17**B. Note that the middle unit **761-30** adds a destination hierarchy **766-30** (TO_MIDDLE=1) to the middle unit synchronization completion.

Additionally, the middle unit non-arrival counter **762-30** resets the middle unit non-arrival counter **762-30** to the value (16) of the middle unit expectation counter **763-30**.

The middle unit **761-***r* that has received the middle unit synchronization completion to which TO_MIDDLE=1 is added decrements the middle unit non-arrival counter **762-***r* by 1. As a result, the middle unit non-arrival counter **762-***r* decrements to "0".

In FIGS. **18**A and **18**B, the middle unit **761-***r* of the barrier synchronization mechanism **731-***r* detects that the middle unit non-arrival counter **762-***r* decrements to "0", and broadcasts middle unit synchronization completion to the barrier synchronization mechanism **731-***r* specified using the middle unit target ID **764-***r* and the middle unit target mask **765-***r*. Note that the middle unit **761-***r* adds a destination hierarchy **766-***r* (TO_MIDDLE=0) to the middle unit synchronization completion.

More specifically, the middle unit **761-04** broadcasts the middle unit synchronization completion to the barrier synchronization mechanisms **731-00** to **731-07**.

The middle unit **761-0***c* broadcasts the middle unit synchronization completion to the barrier synchronization mechanisms **731-08** to **731-0***f*.

The middle unit **761-14** broadcasts middle unit synchronization completion to the barrier synchronization mechanisms **731-10** to **731-17**.

The middle unit **761-1***c* broadcasts middle unit synchronization completion to the barrier synchronization mechanisms **731-18** to **731-1***f*.

The middle unit **761-24** broadcasts middle unit synchronization completion to the barrier synchronization mechanisms **731-20** to **731-27**.

The middle unit **761-2***c* broadcasts middle unit synchronization completion to the barrier synchronization mechanisms **731-28** to **731-2***f*.

The middle unit **761-34** broadcasts middle unit synchronization completion to the barrier synchronization mechanisms **731-30** to **731-37**.

The middle unit **761-3***c* broadcasts middle unit synchronization completion to the barrier synchronization mechanisms **731-38** to **731-3***f*.

The middle unit non-arrival counter **762-***r* resets the middle unit non-arrival counter **762-***r* to the value (4) of the middle unit expectation counter **763-***r*.

The top unit **771-***s* that has received the middle unit synchronization completion to which TO_MIDDLE=0 is added decrements the top unit non-arrival counter **772-***s* by 1. As a result, the top unit non-arrival counter **772-***s* decrements to "0".

The top unit **771-***s* inverts the value of the shared unit barrier state **742-***s* upon detecting that the top unit non-arrival counter **772**-*s* decrements to "0". As a result, the value of the shared unit barrier state **742**-*s* changes from "0" to "1".

Each of the hardware threads checks the shared unit barrier state **742**-*s* of the barrier synchronization mechanism **731**-*s*, including a bitmap written when the hardware thread arrives at a barrier synchronization point, verifies that the value of the shared unit barrier state **742**-*s* becomes equal to that written to the bitmap, determines that the barrier synchronization is complete, and resumes the process up to the next barrier synchronization point.

With the barrier synchronization mechanism according to the third embodiment, synchronization among barrier banks can be implemented with a simple configuration.

As described above, in the barrier synchronization of two hierarchies in the first embodiment, n^2 communications occur if n=the total number of barrier banks is assumed, and the number of communications of the barrier synchronization of 3 hierarchies in the second embodiment is n*(m2+1) if m2=the number of barrier bank groups of the second hierarchy is assumed.

The number of communications in synchronization among barrier banks of 4 hierarchies in the third embodiment is 2n+m2*m3 if m3=the number of barrier bank groups of the third hierarchy is assumed, whereby the number of communications is further reduced.

With the barrier synchronization according to the third embodiment, the number of communications can be further reduced by performing synchronization among barrier banks of 4 hierarchies, whereby a network can be prevented from getting congested.

Fourth Embodiment

FIG. **20** illustrates a configuration of a CPU according to a fourth embodiment.

The CPU **801** corresponds to the CPU **401** of FIG. **2**.

The CPU **801** includes processor cores **821**-*a* (a=1 to 4) and a barrier synchronization mechanism **831**. Moreover, the processor cores **821**-*a* and the barrier synchronization mechanism **831** are included in a barrier bank **811**, which is a minimum unit of barrier bank synchronization. The processor cores **821**-*a* and the barrier synchronization mechanism **831** are interconnected by a bus.

Each of the processor cores **821**-*a* has a simultaneous multi-threading function, and includes hardware threads **822**-*a*-*b* (b=1, 2) for executing a thread.

Since the hardware threads **822** have a function similar to that of the hardware threads **622** of FIG. **5**, their explanations are omitted.

The barrier synchronization mechanism **831** controls the barrier synchronization, and is implemented, for example, with a hardware circuit and a processor.

The barrier synchronization mechanism **831** includes a shared unit **841**, a bottom unit **851**, a middle unit **861** and a top unit **871**.

The shared unit **841** includes a shared unit barrier state **842**, a BANKID **843**, a SYNCID **844** and a barrier type (BTYPE) **845**.

Since the shared unit barrier state **842**, the BANKID **843** and the SYNCID **844** have a function similar to that of the shared unit barrier state **642**, the BANKID **643** and the SYNCID **644** illustrated in FIG. **5**, their explanations are omitted.

The barrier type **845** indicates a type of barrier synchronization performed by the barrier synchronization mechanism **831**. The barrier synchronization mechanism **831** executes a barrier synchronization process according to the barrier type **845**. Namely, the bottom unit **851**, the middle unit **861** and the top unit **871** execute a process according to the barrier type **845**. The barrier type **845** is, for example, "intra-bank", indicating that synchronization within a barrier bank is performed, or "inter-bank", indicating that synchronization among barrier banks is performed.

The bottom unit **851** includes a bottom unit barrier state **852**, a bitmap group **853**, a bottom unit target ID **854**, a bottom unit target mask **855**, and a bottom unit destination hierarchy **866**.

Since the bottom unit barrier state **852**, the bitmap group **853**, the bottom unit target ID **854** and the bottom unit target mask **855** respectively have a function similar to that of the bottom unit barrier state **652**, the bitmap group **653**, the bottom unit target ID **654** and the bottom unit target mask **655** illustrated in FIG. **5**, their explanations are omitted.

The bottom unit destination hierarchy **866** indicates a processing unit (middle unit or top unit) for processing received bottom unit barrier synchronization completion. The bottom unit destination hierarchy **866** is "1" or "0". "1" indicates that the middle unit **861** that has received the bottom unit synchronization completion executes a process for the reception of the bottom unit synchronization completion. "0" indicates that the top unit **871** that has received the bottom unit synchronization completion executes a process for the reception of the bottom unit synchronization completion.

The bottom unit **851** inverts the value of the bottom unit barrier state **852** if values of all bitmaps of the bitmap group **853** become equal and different from the bottom unit barrier state **852**. Namely, the bottom unit barrier state **852** becomes equal to the values of the bitmaps of the bitmap group **653**.

Moreover, the bottom unit **851** executes the following process (1) or (2) according to the barrier type **845**.

(1) Case where the Barrier Type **845** is "Intra-Bank"

The bottom unit **851** inverts the value of the shared unit barrier state **842**. Namely, the value of the shared unit barrier state **842** and that of the bottom unit barrier state **852** become equal.

(2) Case where the Barrier Type **845** is "Inter-Bank"

The bottom unit **851** broadcasts bottom unit barrier synchronization completion to barrier synchronization mechanisms specified using the bottom unit target ID **854** and the bottom unit target mask **855**. If a SYNCID **844** is set, the bottom unit **851** adds the SYNCID **844** to the bottom unit barrier synchronization completion, and broadcasts the bottom unit barrier synchronization completion. Moreover, the bottom unit **851** adds a value of the bottom unit destination hierarchy **856** to the bottom unit barrier synchronization completion. For example, if the bottom unit destination hierarchy **856** is "1", the bottom unit **851** adds TO_MIDDLE=1 to the bottom unit barrier synchronization completion. Alternatively, if the bottom unit destination hierarchy **856** is "0", the bottom unit **851** adds TO_MIDDLE=0 to the bottom unit barrier synchronization completion.

The middle unit **861** includes a middle unit non-arrival counter **862**, a middle unit expectation counter **863**, a middle unit target ID **864**, a middle unit target mask **865**, and a middle unit destination hierarchy **866**.

The middle unit non-arrival counter **862** counts the number of barrier synchronization mechanisms that have not transmitted the bottom unit barrier synchronization completion among barrier synchronization mechanisms for which the barrier synchronization is checked by the middle unit **861**, and holds the counted value. The middle unit non-arrival counter **862** decrements its value by 1 upon receipt of the bottom unit barrier synchronization completion to which TO_MIDDLE=1 is added. Moreover, the middle unit non-arrival counter **862** decrements its value by 1 upon receipt of the middle unit barrier synchronization completion to which TO_MIDDLE=1 is added.

Additionally, the middle unit non-arrival counter **862** decrements its value by 1 if an added SYNCID matches the SYNCID **844** when the SYNCID is added to the middle unit barrier synchronization completion to which TO_MIDDLE=1 is added or the bottom unit barrier synchronization completion to which TO_MIDDLE=1 is added. The middle unit non-arrival counter **862** does not decrement its value if the added SYNCID does not match the SYNCID **844** when the SYNCID is added to the middle unit barrier synchronization completion to which TO_MIDDLE=1 is added or the bottom unit barrier synchronization completion to which TO_MIDDLE=1 is added. Namely, the middle unit non-arrival counter **862** executes a process by regarding the bottom unit barrier synchronization completion and the middle unit barrier synchronization completion as a valid or invalid signal depending on whether or not the SYNCID added to the middle unit barrier synchronization completion or the bottom unit barrier synchronization completion matches the SYNCID **844**.

The middle unit expectation counter **863** is information indicating the number of barrier synchronization mechanisms for which the barrier synchronization is checked by the middle unit **861** and holds its value.

The middle unit target ID **864** is information indicating a barrier synchronization mechanism to which the middle unit **861** broadcasts barrier synchronization completion.

The middle unit target mask **865** is information for specifying a position of a don't-care bit for the middle unit target ID **864**. Namely, the middle unit target mask **865** indicates a position of a bit that can take an arbitrary value in the middle unit target ID **864**.

The middle unit destination hierarchy **866** indicates a processing unit (middle unit or top unit) for processing received middle unit barrier synchronization completion. The middle unit destination hierarchy **866** is "1" or "0". "1" indicates that the middle unit **861** that has received the middle unit synchronization completion executes a process for the reception of the middle unit synchronization completion. "0" indicates that the top unit **871** that has received the middle unit synchronization completion executes a process for the reception of the middle unit synchronization completion.

The middle unit **861** broadcasts the middle unit barrier synchronization completion to barrier synchronization mechanisms specified using the middle unit target ID **864** and the middle unit target mask **865** if the middle unit non-arrival counter **862** decrements to "0". The middle unit **861** adds the value of the middle unit destination hierarchy **866** to the middle unit barrier synchronization completion. For example, if the middle unit destination hierarchy **866** is "1", the middle unit **761** adds TO_MIDDLE=1 to the middle unit barrier synchronization completion. Alternatively, if the middle unit destination hierarchy **866** is "0", the middle unit **761** adds TO_MIDDLE=0 to the middle unit barrier synchronization completion. Moreover, the middle unit **861** further adds a SYNCID **844** to middle unit barrier synchronization completion if the SYNCID **844** is set.

Additionally, the middle unit **861** resets the value of the middle unit non-arrival counter **862** to that of the middle unit expectation counter **863** if the middle unit non-arrival counter **862** decrements to "0".

The middle unit **861** does not run even when barrier synchronization completion is received since the middle unit **861** is invalid if the barrier type **845** is "intra-bank". Further, the middle unit **861** does not run even when barrier synchronization completion is received since the middle unit **861** is invalid if the barrier type **845** is "inter-bank" and the bottom unit destination hierarchy **856** is "0".

The top unit **871** includes a top unit non-arrival counter **872** and a top unit expectation counter **873**.

The top unit non-arrival counter **872** counts the number of barrier synchronization mechanisms that have not transmitted middle unit barrier synchronization completion to which TO_MIDDLE=0 is added or bottom unit barrier synchronization completion to which TO_MIDDLE=0 is added among barrier synchronization mechanisms for which the barrier synchronization is checked by the top unit **871**, and holds the counted value.

The top unit non-arrival counter **872** decrements its value by 1 upon receipt of the middle unit barrier synchronization completion to which TO_MIDDLE=0 is added or the bottom unit barrier synchronization completion to which TO_MIDDLE=0 is added.

Additionally, the top unit non-arrival counter **872** decrements its value by 1 if an added SYNCID matches the SYNCID **844** when the SYNCID is added to the middle unit barrier synchronization completion to which TO_MIDDLE=0 is added or the bottom unit barrier synchronization completion to which TO_MIDDLE=0 is added. Alternatively, the top unit non-arrival counter **872** does not decrement its value if the added SYNCID does not match the SYNCID **844** when the SYNCID is added to the middle unit barrier synchronization completion to which TO_MIDDLE=0 is added or the bottom unit barrier synchronization completion to which TO_MIDDLE=0 is added. Namely, the top unit non-arrival counter **872** executes a process by regarding the bottom unit barrier synchronization completion and the middle unit barrier synchronization completion as a valid or invalid signal depending on whether or not a SYNCID added to the middle unit barrier synchronization completion or the bottom unit barrier synchronization completion matches the SYNCID **84**.

The top unit expectation counter **873** is information indicating the number of barrier synchronization mechanisms for which the barrier synchronization is checked by the top unit **871** and holds its value.

The top unit **871** inverts the value of the shared unit barrier state **842** if the top unit non-arrival counter **872** decrements to "0". Moreover, the top unit **871** resets the value of the top unit non-arrival counter **872** to that of the top unit expectation counter **873** if the top unit non-arrival counter **872** decrements to "0".

The top unit **871** is invalid if the barrier type **845** is "intra-bank", and does not run even upon receipt of barrier synchronization completion.

With the barrier bank mechanism according to the fourth embodiment, both conventional synchronization within a barrier bank and synchronization among barrier banks according to the first to the third embodiments can be performed by settings.

Namely, the barrier synchronization mechanism **831** executes a process similar to the barrier synchronization mechanisms **1003**, **531**, **631** and **731** by setting the barrier type **845**, the bottom unit destination hierarchy **856** and the middle unit destination hierarchy **866**.

Accordingly, a user makes suitable settings according to a configuration of a server, whereby an optimum barrier synchronization hierarchy and an optimum set of barrier banks can be set.

A plurality of examples of setting the barrier type **845**, the bottom unit destination hierarchy **856** and the middle unit destination hierarchy **866** in the barrier synchronization mechanism **831** according to the fourth embodiment, and a plurality of examples of operations of the barrier synchronization mechanism **831** are described next.

FIG. **21**A illustrates a first setting example of the barrier synchronization mechanism according to the fourth embodiment.

The first setting example is used to perform synchronization within a barrier bank.

In the first setting example, the barrier type **845** is "intra-bank".

Assume that the BANKID **843** and the SYNCID **844** are set to suitable values according to the barrier synchronization mechanism **831**.

Additionally, since the barrier type **845** is "intra-bank", the middle unit **861** and the top unit **871** are invalid.

The bottom unit **851** inverts the value of the bottom unit barrier state **852** if values of all bitmaps of the bitmap group **853** become equal and different from the bottom unit barrier state **852**. Namely, the value of the bottom unit barrier state **852** becomes equal to the bitmaps of the bitmap group **653**.

Then, the bottom unit **851** inverts the value of the shared unit barrier state **842**. Namely, the value of the shared unit barrier state **842** and that of the bottom unit barrier state **852** become equal.

By using the first setting example, barrier synchronization within a barrier bank, which is described in BACKGROUND, can be performed.

FIG. **21**B illustrates a second setting example of a barrier synchronization mechanism according to the fourth embodiment.

The second setting example is used to perform synchronization among barrier banks of two hierarchies.

In the second setting example, the barrier type **845** is "inter-bank".

Additionally, the bottom unit destination hierarchy **856** is "0".

Furthermore, assume that the BANKID **843**, the SYNCID **844**, the bottom unit target ID **854**, the bottom unit target mask **855**, the top unit non-arrival counter **872**, and the top unit expectation counter **873** are set to suitable values according to the barrier synchronization mechanism **831**.

Since the barrier type **845** is "inter-bank" and the bottom unit destination hierarchy **856** is "0", the middle unit **861** is invalid.

The bottom unit **851** inverts the value of the bottom unit barrier state **852** if values of all bitmaps of the bitmap group **853** become equal and different from the bottom unit barrier state **852**.

The bottom unit **851** broadcasts bottom unit barrier synchronization completion to barrier synchronization mechanisms specified using the bottom unit target ID **854** and the bottom unit target mask **855**. The bottom unit **851** adds a SYNCID **844** and TO_MIDDLE=0 to the bottom unit barrier synchronization completion, and broadcasts the bottom unit barrier synchronization completion.

The top unit non-arrival counter **872** receives the bottom unit barrier synchronization completion to which TO_MIDDLE=0 is added. The top unit non-arrival counter **872** decrements its value by 1 if the SYNID added to the bottom unit barrier synchronization completion matches the SYNCID **844**. Alternatively, the top unit non-arrival counter **872** does not decrement its value if the SYNCID added to the bottom unit barrier synchronization completion does not match the SYNCID **844**.

The top unit **871** inverts the value of the shared unit barrier state **842** if the top unit non-arrival counter **872** decrements to "0". Moreover, the top unit **871** resets the value of the top unit non-arrival counter **872** to that of the top unit expectation counter **873** if the top unit non-arrival counter **872** decrements to "0".

With the second setting example, synchronization among barriers of two hierarchies referred to in the first embodiment can be performed.

FIG. **21**C illustrates a third setting example of a barrier synchronization mechanism according to the fourth embodiment.

The third setting example is used to perform synchronization among barrier banks of 3 hierarchies.

In the third setting example, the barrier type **845** is "inter-bank".

The bottom unit destination hierarchy **856** is "1".

The middle unit destination hierarchy **866** is "0".

Assume that the BANKID **843**, the SYNCID **844**, the bottom unit target ID **854**, the bottom unit target mask **855**, the middle unit non-arrival counter **862**, the middle unit expectation counter **863**, the middle unit target ID **864**, the middle unit target mask **865**, the top unit non-arrival counter **872**, and the top unit expectation counter **873** are set to suitable values according to the barrier synchronization mechanism **831**.

The bottom unit **851** inverts the value of the bottom unit barrier state **852** if values of all bitmaps of the bitmap group **853** become equal and different from the bottom unit barrier state **852**.

The bottom unit **851** broadcasts bottom unit barrier synchronization completion to barrier synchronization mechanisms specified using the bottom unit target ID **854** and the bottom unit target mask **855**. The bottom unit **851** adds a SYNCID **844** and TO_MIDDLE=1 to the bottom unit barrier synchronization completion, and broadcasts the bottom unit barrier synchronization completion.

The middle unit non-arrival counter **862** receives the bottom unit barrier synchronization completion to which TO_MIDDLE=1 is added. The middle unit non-arrival counter **862** decrements its value by 1 if the SYNCID added to the bottom unit barrier synchronization completion matches the SYNCID **844**. Alternatively, the middle unit non-arrival counter **862** does not decrement its value if the SYNCID added to the bottom unit barrier synchronization completion does not match the SYNCID **844**.

The middle unit **861** broadcasts middle unit barrier synchronization completion to barrier synchronization mechanisms specified using the middle unit target ID **864** and the middle unit target mask **865** if the middle unit non-arrival counter **862** decrements to "0". The middle unit **861** adds a SYNCID **844** and TO_MIDDLE=0 to the middle unit barrier synchronization completion. Moreover, the middle unit **861** resets the value of the middle unit non-arrival counter **862** to that of the middle unit expectation counter **863** if the middle unit non-arrival counter **862** decrements to "0".

The top unit non-arrival counter **872** receives the middle unit barrier synchronization completion to which TO_MIDDLE=0 is added. The top unit non-arrival counter **872** decrements its value by 1 if the SYNCID added to the middle unit barrier synchronization completion matches the SYNCID **844**. The top unit non-arrival counter **872** does not decrement its value if the SYNCID added to the middle unit barrier synchronization completion does not match the SYNCID **844**.

The top unit **871** inverts the value of the shared unit barrier state **842** if the top unit non-arrival counter **872** decrements to "0". Moreover, the top unit **871** resets the value of the top unit non-arrival counter **872** to that of the top unit expectation counter **873** if the top unit non-arrival counter **872** decrements to "0".

With the third setting example, the synchronization among barriers of three hierarchies referred to in the second embodiment can be performed.

Here, a range and the number of communications (a notification of barrier synchronization completion), which occur when various types of barrier synchronizations are performed, in the server according to the embodiment illustrated in FIG. **2** are described.

FIGS. **22**A to **22**C illustrate barrier synchronization in the server according to the embodiment.

In FIGS. **22**A to **22**C, the CPUs **401**-*i*-*j* respectively include two barrier banks.

Note that a CPU is also referred to as a chip.

In FIG. **22**A, example 1) barrier synchronization within one barrier bank, and example 2) barrier synchronization of 1 chip (two barrier banks) are described.

Example 1

Barrier Synchronization within One Barrier Bank

In example 1, barrier synchronization is performed within the barrier bank **411-1-1-1**. In this case, a communication outside the barrier bank **411-1-1-1** does not occur.

Example 2

Barrier Synchronization of 1 Chip (Two Barrier Banks)

In example 2, synchronization among barrier banks is performed between the barrier banks **411-2-1-1** and **411-2-1-2**. In this case, the barrier banks can be synchronized within the CPU **401-2-1**.

Accordingly, a communication outside the CPU **401-2-1** does not occur.

In FIG. **22**B, example 3) barrier synchronization of chips (4 barrier banks), and example 4) barrier synchronization of 1 board (8 barrier banks) are described.

Example 3

Barrier Synchronization of 2 Chips (4 Barrier Banks)

In example 3, synchronization among barrier banks is performed between two barrier banks within the CPU **401-1-1** and two barrier banks within the CPU **401-1-2**. Namely, barrier synchronization among 4 barrier banks is performed.

If barrier synchronization among 4 barrier banks is performed with barrier synchronization of two hierarchies, a communication except the communication between the CPUs **401-1-1** and **401-1-2** does not occur.

Example 4

Barrier Synchronization of 1 Board (8 Barrier Banks)

In example 4, barrier synchronization among 8 barrier banks within the system board **201-2** is performed. Here, the barrier synchronization of two hierarchies is performed.

With the barrier synchronization of two hierarchies, the total number of signals issued for one barrier synchronization is a total of the number of broadcast from the barrier banks.

Accordingly, the total number of signals issued for one barrier synchronization is 8*8=64.

In FIG. **22**C, example 5) barrier synchronization (32 barrier banks) of the entire server is described.

Example 5

Barrier Synchronization in the Entire Server (32 Barrier Banks)

In example 5, the barrier synchronization is performed in the entire server **101**.

If the barrier synchronization of the entire server **101** is performed with the barrier synchronization of two hierarchies, the total number of signals issued for one barrier synchronization is the number of broadcast from the barrier banks.

Accordingly, the total number of signals issued for one barrier synchronization is 32*32=1024. Moreover, the number of signals transmitted via the switch **301** among issued signals is 32*24=768.

With the barrier synchronization of 3 hierarchies, the total number of signals issued for one barrier synchronization is the number of broadcast to a limited range in the second hierarchy (one barrier bank within each of the CPUs **401-1-3**, **401-2-3**, **401-3-3** and **401-4-3**)+the number of broadcast to a limited range in the third hierarchy (barrier banks within the same system board).

Namely, the 32 barrier banks notify four barrier banks of the second hierarchy of barrier synchronization completion, and the four barrier banks of the second hierarchy notify eight barrier banks within the system board where the local barrier bank is present of the barrier synchronization completion.

Accordingly, the total number of signals issued for one barrier synchronization is 32*4+4*8=160. Moreover, the number of signals transmitted via the switch **301** among issued signals is 32*3=96.

If barrier synchronization is performed among many barrier banks, a hierarchy is added as in the barrier synchronization of 3 hierarchies in the above described example 5, so that the number of barrier synchronization signals issued in the entire system can be reduced. This effectively works in a case where a shared communication path exists such as the above described switch tends to become a performance bottleneck.

Since the barrier synchronization mechanism according to the fourth embodiment can perform a plurality of synchronization methods, an optimum synchronization method can be selected according to a latency and a bandwidth of a communication path.

All examples and conditional language provided herein are intended for pedagogical purposes to aid the reader in understanding the invention and the concepts contributed by the inventor to further the art, and are not to be construed as limitations to such specifically recited examples and conditions, nor does the organization of such examples in the specification relate to a showing of the superiority and inferiority of the invention. Although one or more embodiments of the present invention have been described in detail, it should be understood that the various changes, substitutions, and alterations could be made hereto without departing from the spirit and scope of the invention.

What is claimed is:

1. An information processing device, comprising:

a plurality of barrier banks; and

one or more processors including at least one of the plurality of barrier banks, wherein

each of the plurality of barrier banks comprises

one or more hardware threads configured to execute a thread, and

a barrier synchronization mechanism configured to perform barrier synchronization of the plurality of barrier banks,

the barrier synchronization mechanism comprises

a shared unit comprising a barrier state indicating whether or not the synchronization is complete,

a bottom unit comprising a bitmap indicating that each of the one or more hardware threads has arrived at a synchronization point, and

a top unit comprising a non-arrival counter indicating the number of barrier banks yet to be synchronized among the plurality of barrier banks for which barrier synchronization is to be performed,

the bottom unit checks the bitmap, and notifies a barrier bank specified using target information, and mask information which is information for specifying a position of a don't-care bit for the target information of bottom unit synchronization completion when all the one or more hardware threads have arrived at a barrier synchronization point,

the non-arrival counter decrements a value of the non-arrival counter by 1 upon receipt of the bottom unit synchronization completion, and

the top unit sets the barrier state to a value indicating synchronization completion when the non-arrival counter decrements to 0.

2. A barrier synchronization method executed by an information processing device, including a plurality of barrier banks and one or more processors including at least one of the plurality of barrier banks, for performing synchronization of the plurality of barrier banks, each of the plurality of barrier banks including one or more hardware threads configured to execute a thread and a barrier synchronization mechanism configured to perform barrier synchronization of the plurality of barrier banks, the method comprising:

checking a bitmap indicating that each of the one or more hardware threads has arrived at a synchronization point;

notifying a barrier bank specified using target information, and mask information which is information for specifying a position of a don't-care bit for the target information of bottom unit synchronization completion when all the one or more hardware threads have arrived at a barrier synchronization point;

decrementing, by 1, a non-arrival counter indicating the number of barrier banks yet to be synchronized among the plurality of barrier banks for which the barrier synchronization is to be performed upon receipt of the bottom unit synchronization completion; and

setting a barrier state included in a shared unit and indicating whether or not the barrier synchronization of the plurality of barrier banks is complete to a value indicating synchronization completion when the non-arrival counter decrements to 0.

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